Supermarket food waste

Prevention and management with the focus on reduced waste for reduced carbon footprint

Mattias Eriksson
Faculty of Natural Resources and Agricultural Sciences
Department of Energy and Technology
Uppsala

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Abstract

Food waste occurs along the entire food supply chain and gives rise to great financial losses and waste of natural resources. The retail stage of the supply chain contributes significant masses of waste. Causes of this waste need to be identified before potential waste reduction measures can be designed, tested and evaluated. Therefore this thesis quantified retail food waste and evaluated selected prevention and valorisation measures, in order to determine how the carbon footprint of food can be reduced by decreasing food waste in supermarkets.

Food waste was quantified in six supermarkets in the Uppsala-Stockholm region of Sweden. Data were recorded over five years between 2010 and 2014 by the retail company in a daily waste recording procedure. In addition, suppliers contributed data on deliveries and rejections. The main suppliers contributed data on wholesale pack size and shelf-life, which allowed the relationship between these and their effect on waste to be analysed. Life cycle assessment was used to investigate the carbon footprint associated with production and distribution of food and managing the waste.

The wasted mass was dominated by fresh fruit and vegetables and rejection on delivery was the main reason for this food being wasted. Expressed in terms of carbon footprint rather than mass, the relative importance of meat waste increased and that of fruit and vegetables decreased.

A reduction in storage temperature to prolong shelf-life proved to have the potential to reduce waste in all supermarket departments studied. However, when the temperature reduction was achieved by extended use of the current electricity mix, a net lowering of carbon footprint was only found for the meat department. For food products with a high carbon footprint, *e.g.* beef, there was much greater potential to lower the carbon footprint by preventing waste through source reduction than by upgrading the waste management option. If food waste cannot be prevented, donation to charity and anaerobic digestion of the waste were found to have the greatest potential to reduce the carbon footprint, depending on the substituted bread value and biogas potential, respectively. This follows the EU waste hierarchy, although there are variations from the trend of more favourable options at higher levels of the hierarchy.

Keywords: Food waste, Supermarket, Prevention, Valorisation, Life cycle assessment

Author's address: Mattias Eriksson, SLU, Department of Energy and Technology,
P.O. Box 7032, 750 07 Uppsala, Sweden
E-mail: Mattias.Eriksson@slu.se

Dedication

To all the food waste geeks out there

We cannot solve our problems with the same thinking we used when we created them.
Albert Einstein

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List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Eriksson, M., Strid, I. & Hansson, P-A. (2012). Food losses in six Swedish retail stores - wastage of fruit and vegetables in relation to quantities delivered. *Resources, Conservation and Recycling* 68, 14-20.

II Eriksson, M., Strid, I. & Hansson, P.-A. (2014). Wastage of organic and conventional meat and dairy products - a case study from Swedish retail. *Resources, Conservation and Recycling* 83, 44-52.

III Scholz, K., Eriksson, M. & Strid, I. (2015). Carbon footprint of supermarket food waste. *Resources, Conservation and Recycling* 94, 56-65.

IV Eriksson, M., Strid, I. & Hansson, P.-A. (2015). Food waste reduction in supermarkets – net costs and benefits of reduced storage temperature. *(Submitted manuscript)*.

V Eriksson, M., Strid, I. & Hansson, P.-A. (2015). Carbon footprint of food waste management options in the waste hierarchy - a Swedish case study. *Journal of Cleaner Production* 93, 115-125.

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The contribution of Mattias Eriksson to Papers I-V was as follows:

I	Planned the paper in cooperation with the co-authors. Performed data collection, observations in stores, physical measurements and analysis of data. Interpreted the data and wrote the manuscript together with the co-authors.
II	Planned the paper in cooperation with the co-authors. Performed data collection, calculations and analysis of data. Interpreted the data and wrote the manuscript with input from the co-authors.
III	Planned the paper together with the co-authors. Supervised the data collection, calculations and analysis of data. Provided input to the writing of the manuscript and was corresponding author.
IV	Planned the study. Performed data collection, calculations and analysis of data. Interpreted the data and wrote the manuscript with input from the co-authors.
V	Planned the study with input from the co-authors. Performed data collection, calculations and analysis of data. Interpreted the data and wrote the manuscript with input from the co-authors.

Abbreviations

CF	Carbon footprint
CO_2e	Carbon dioxide equivalents
EAN	European Article Number
FAO	Food and Agricultural Organisation of the United Nations
FFV	Fresh fruit and vegetables
GWP	Global Warming Potential
LCA	Life Cycle Assessment
MFA	Material/mass flow analysis
MLR	Multiple linear regression
MOS	Minimum order size
PLU	Price look-up
SL	Shelf-life
T	Turnover
WFD	Waste Framework Directive

1 Introduction

Providing enough food for the world's growing population is easy, but doing this at an acceptable cost to the planet is more challenging (Nature, 2010). This challenge requires changes in the way food is produced, stored, processed, distributed and consumed. Godfrey *et al*. (2010) suggest five major strategies to meet these challenges: Closing the yield gap; increasing production limits by genetic modification; expanding aquaculture; dietary changes; and reducing waste. These all involve utilising the full potential of the production system so that more food can be consumed without increased resource demand at the same rate. Reducing waste is unique in this context, since it focuses on food that is already produced, but not consumed for various reasons. Since reduced waste of edible food is also one of the least controversial ways to make the food supply chain more productive, it has the potential to be used immediately to decrease the competition for natural resources that could be saved for future production to avoid a future food crisis (Nellemann *et al.*, 2009).

1.1 The food waste problem

Waste, loss or spoilage of food is an efficiency issue that has attracted increasing attention from the media, researchers, politicians, companies and the general public in recent years. Although food waste seems like a simple problem, the solution "to just stop throwing it away" is much more complex than would appear at first glance. This is because food waste is not just a problem, but also a solution to other problems, such as public health or economic profit, which are often a higher priority. Food is also wasted for a large number of reasons, which makes it difficult to find a 'quick fix' to reduce food waste once and for all. In many countries the food waste in itself creates a problem if it is dumped in landfill and generates methane. In other countries, Sweden included, landfilling of organic waste is prohibited and surplus food is considered a resource that can be used for biogas production or for feeding people in need. It is therefore not the wasted food that should be the main concern, but the wasteful behaviour that results in unnecessary food production.

The complexity of the food waste issue also links it to the three parts of sustainable development: economics, social issues and environmental impact. This does not mean that reduced food waste automatically results in sustainable development, but reducing unnecessary food waste has the potential to make an important contribution and also has a high symbolic value. Food waste can be related to waste of money (FAO, 2013) and natural resources (Steinfeldt *et al.*, 2006; Garnett, 2011), but also has moral implications in relation to food security (Stuart, 2009; FAO, 2012). The political will to work on food waste reduction can be seen as rational and positive, since there are few good arguments for keeping on wasting food. This has resulted in several goals on waste reduction among companies (Tesco, 2014), states (Rutten, 2013) and international organisations (EC, 2011). As pointed out by Garnett (2011), reducing food waste is not the only way to make the food supply chain more sustainable, but it has the potential to save money too and is less controversial than *e.g.* reducing meat consumption.

One of the problems closely associated with food waste is food security and the moral implications of throwing away food while people in parts of the word are starving (Stuart, 2009). However, just finishing off the food on one’s plate will not make a starving person any happier, since the problem of starvation is also connected to the global economy and how resources are distributed around the world. Therefore a reduction in food waste in a supermarket in Sweden will not necessarily lead to less starvation in the world, but may have an indirect influence due to reduced demand for the finite resources needed for food production.

1.2 The role of supermarkets in the food supply chain

The loss of food is a problem along the whole food supply chain but since more value, in terms of both money and resources, is added for every step in the food supply chain, waste represents more loss of value at the end of the chain when more subprocesses have been in vain (Eriksson & Strid, 2013; Strid *et al.*, 2014). This means that the potential economic benefits of reducing waste per unit mass are higher in later stages of the value chain (SEPA, 2012). However for some products, especially those of animal origin, much of the life cycle emissions are generated already at farm level (Röös, 2013) and food waste reduction will therefore have the same high reducing effect along the whole supply chain after farm level.

Supermarkets are located close to the end of the supply chain and also collect large quantities of food in a limited number of physical locations. Therefore these are potentially good targets for waste reduction measures, even though supermarkets contribute a relatively small share of waste in comparison with other stages in the food supply chain (Jensen *et al.*, 2011a; FAO, 2011; Göbel *et al.*, 2012). Recent studies of food waste in supermarkets mostly focus on describing the quantity of waste, problems causing it and how it could be given to charity in order to avoid waste (Alexander & Smaje, 2008; Buzby *et al.*, 2009; 2011; Lee & Willis, 2010; Gustavsson & Stage, 2011; Stenmarck *et al.*, 2011; Lebersorger & Schneider, 2014). There is therefore a need to take this problem one step further and investigate waste prevention and waste valorisation measures, and the potential to reduce the environmental, social and economic impacts related to food waste.

This thesis focuses on waste quantification in order to move further towards finding potential ways of preventing food waste in supermarkets or, when prevention is not possible, reducing the negative outcome regarding the carbon footprint of handling food waste. Such knowledge could be used to reduce the negative impact of the food supply chain and thereby contribute to sustainable development for future generations.

2 Objectives and structure of the thesis

2.1 Objectives

The overall aim of this thesis was to provide new information on how to reduce food waste and the carbon footprint associated with wasted food. Specific objectives were to describe the quantity of wasted food in supermarkets in terms of mass and carbon footprint, analyse some risk factors that can increase waste and perform a theoretical evaluation of various waste valorisation and prevention measures.

2.2 Structure of the thesis

In order to fulfil these objectives, the thesis was structured according to the four steps of waste reduction shown in Figure 1. The first step is to quantify the extent of the problem and potential hotspots. The quantities defined can then be analysed to find causes and risk factors influencing waste generation. With this information, efficient measures can be designed to reduce the risk factors. When effective measures have been introduced, they can be evaluated in terms of how much they save by reducing waste and how much they cost.

Papers I and II focus on the wasted mass in supermarkets, concentrating on fruit and vegetables and organic meat, deli, cheese and dairy products. The carbon footprint associated with production and distribution of the wasted food is the main focus in Paper III.

Paper II also examines causes relating to turnover, shelf-life and minimum order size. This relationship is further developed in Paper IV, where it is used to design and theoretically evaluate a waste prevention measure of increasing the shelf-life by reducing the storage temperature.

Several waste valorisation options are evaluated in Paper V, together with theoretic measures regarding donation of surplus food and its use in animal feed.

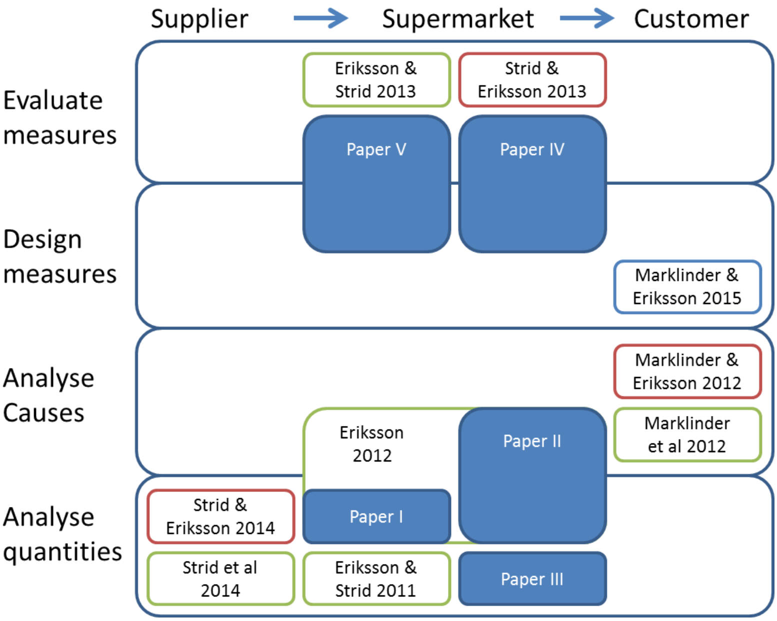

Figure 1. Schematic diagram of Papers I-V in this thesis and related publications. The vertical levels illustrate different steps in the waste reduction process and the horizontal segments illustrate different stages in the food supply chain.

2.3 Other publications by the author relating to the thesis

During the work of this thesis, a number of ideas or problems in need of further investigation were identified. It was not possible to explore all of these ideas in Papers I-V and therefore a number of other papers have been written based on the material and experience collected. These related publications are included together with Papers I-V in Figure 1 and are listed with a short description in Table 1. Only publications where the author of this thesis was co-author and where the investigation centred on waste in the food supply chain are shown.

Table 1. *Brief summary of other publications related to the work in this thesis*

Reference	Type of publication	Short description
Eriksson & Strid (2011)	Technical report	Pre-study of Paper I quantifying in-store waste of fruit and vegetables, cheese, dairy, deli and meat during 2010.
Marklinder *et al*. (2012) Marklinder & Eriksson (2012) Marklinder & Eriksson (2015)	Technical report Conference paper Research paper	The 2011 mass experiment of the Swedish version of researchers' night, where school children were engaged to measure the temperature in several places in domestic refrigerators.
Eriksson (2012)	Licentiate thesis	Summary of the findings of Papers I and II.
Strid & Eriksson (2013)	Conference paper	Evaluation of a pilot test where supermarkets froze down meat cuts and sold them to a restaurant.
Eriksson & Strid (2013)	Technical report	Describing and calculating the potential savings and cost of six food waste reduction measures in supermarkets.
Strid *et al*. (2014) Strid & Eriksson (2014)	Technical report Conference paper	Investigating losses in Swedish production and distribution of iceberg lettuce.

3 Background

Food is wasted in all stages of the food supply chain, but since the food distribution system is large and complex, there are significant variations in quantities over time, between products and between different types of businesses. Due to the complexity of the food supply chain there is a need for many large studies to fully cover the quantities of waste generated and the underlying causes, and ultimately what could be done to reduce the negative consequences of food waste. This chapter presents some existing knowledge about food waste in general, but with the emphasis on food waste in supermarkets.

3.1 Definitions of food waste in the literature

In order to quantify food waste, there is first a need to define what the quantification should include. Since food consists of a large and diverse group of products, it is complicated to find an easy definition that fits all purposes. Moreover, waste and the process that turns food into waste include many situations and perspectives. Therefore the literature is full of expressions such as “food loss” (*e.g*. FAO, 2011; Strid & Eriksson, 2014), “food waste” (*e.g*. DEFRA, 2010), “post-harvest loss” (*e.g*. Hodges *et al*., 2011), “food and drink waste” (*e.g*. Griffin *et al.*, 2009; Lee & Willis, 2010) and “spoilage” (*e.g*. Lundquist *et al*., 2008). According to Östergren *et al*. (2014), the list may even be much longer. Some of these expressions are overlapping and some are used to define different type of waste.

One problem with developing the definition of food waste, as explained by Schneider (2013b), is the commonly used EU definition of food (EC, 2002).

This legal definition[1] excludes plants prior to harvesting. Therefore plants which are not harvested due *e.g.* to low market price are not counted as food waste (Schneider, 2013). This creates a problem, since the food waste issue does not necessarily start at harvest. Therefore Östergren *et al.* (2014) propose a definition that includes products prior to harvest, which is a clear distinction from many other studies. Their definition of food waste[2] uses a definition of the food supply chain[3], which includes products ready for harvest or slaughter, not just products defined as food by EC (2002). Since the definition by Östergren *et al.* (2014) also includes inedible parts of food products, it covers as subcategories other commonly used categorisations such as “avoidable”, “possibly avoidable” and “unavoidable” food waste (EC, 2010; WRAP, 2011).

The definition used is of course a matter of opinion and as long as it is clearly stated in publications, it does not create problems. Problems appear, however, when quantities of food waste based on different definitions are merged together and used as if defined similarly. An example of this is the Institution of Mechanical Engineers (2013) statement that 30-50% (or 1.2-2 billion metric tonnes (tons)) of all food produced never reaches a human stomach, based on FAO (2011) and Lundquist *et al.* (2008). The problem with this is that Lundquist *et al.* (2008) compare the basic production with what is

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[1] REGULATION (EC) No 178/2002, Article 2, Definition of ‘food’:

For the purposes of this Regulation, ‘food’ (or ‘foodstuff’) means any substance or product, whether processed, partially processed or unprocessed, intended to be, or reasonably expected to be, ingested by humans.

‘Food’ includes drink, chewing gum and any substance, including water, intentionally incorporated into the food during its manufacture, preparation or treatment. It includes water after the point of compliance as defined in Article 6 of Directive 98/83/EC and without prejudice to the requirements of Directives 80/778/EEC and 98/83/EC.

‘Food’ shall not include: (a) feed; (b) live animals unless they are prepared for placing on the market for human consumption; (c) plants prior to harvesting; (d) medicinal products within the meaning of Council Directives 65/65/EEC (1) and 92/73/EEC (2); (e) cosmetics within the meaning of Council Directive 76/768/EEC (3); (f) tobacco and tobacco products within the meaning of Council Directive 89/622/EEC (4); (g) narcotic or psychotropic substances within the meaning of the United Nations Single Convention on Narcotic Drugs, 1961, and the United Nations Convention on Psychotropic Substances, 1971; (h) residues and contaminants.

[2] Food waste is any food, and inedible parts of food, removed from the food supply chain to be recovered or disposed of (including composted, crops ploughed in/not harvested, anaerobic digestion, bio-energy production, co-generation, incineration, disposal to sewer, landfill or discarded to sea).

[3] The food supply chain is the connected series of activities used to produce, process, distribute and consume food. The food supply chain starts when the raw materials for food are ready to enter the economic and technical system for food production or home-grown consumption. This is a key distinction, in that any products ready for harvest or slaughter being removed are within scope, not just those harvested and subsequently not used. It ends when the food is consumed or ‘removed’ from the food supply chain.

eaten to estimate the waste, which means that animal feed is included in waste. FAO (2011), on the other hand, defines food waste and losses as food that was originally meant for human consumption but which unfortunately leaves the human food chain (even if directed to a non-food use). Inclusion of animal feed as a food waste or not has a large impact and could explain the difference between 30% and 50% waste. Stating these values as a range clearly gives the reader a false impression of the size of the waste problem, since the waste can actually be both 30% and 50% at the same time.

3.2 Waste and losses in the food supply chain

Several studies in recent years have attempted to estimate parts of the global food waste and its consequences. According to FAO (2011), approximately one-third of the food produced in the world is wasted, corresponding to 1.3 billion tons of food waste every year. To put this figure into context, FAO (2013) also estimates that this food waste gives rise to greenhouse gases corresponding to 3.3 billion tons of carbon dioxide equivalents (CO_2e) every year, costs around $750 billion annually and guzzles a volume of water equivalent to the annual flow of Russia's Volga River. These figures are of course rough estimates associated with both large variations and insecure data, but clearly much of the food produced in the world is not consumed as intended.

There seems to be a trend in the waste pattern of the whole food supply chain for much of the waste to occur during primary production and in the consumer stage (FAO, 2011; Jensen *et al.*, 2011a; Göbel *et al.*, 2012). The stages in between, including processing, wholesale and retail, contribute smaller amounts in this perspective, which could be the reason why consumers are often the target of waste reduction campaigns and other efforts to reduce food waste (NFA, 2015; WRAP, 2015). However, even if the waste occurring in the retail stage of the supply chain is less than in some other stages, the amounts involved are still enormous, *e.g.* approximately 70 000 tons per year in Sweden (SEPA, 2013) and 4.4 million tons per year in the EU-27 (EC, 2010).

The contribution of the retail sector to waste in the Swedish food supply chain (excluding agriculture) is estimated to be 39 000 tons per year, corresponding to 3.8% (Jensen *et al.*, 2011a). However, that estimate is based only on the organic waste fraction and therefore Stare *et al.* (2013) investigated the mixed waste fraction and upgraded the amount to 67 000 tons per year, corresponding to 6.1% of the whole food supply chain (excluding agriculture). The values presented in Figure 2 are based on data from Jensen *et al.* (2011a) and Stare *et al*. (2013), updated by SEPA (2013) to represent the year 2012. These figures, which can be considered the official Swedish food waste statistics, show that 70 000 tons of food per year are wasted in Swedish supermarkets. Göbel *et al*. (2012) estimated that the retail stage of the German food supply chain contributes 3% of its food waste. This seems low in comparison with the Swedish estimate of 6.1% (Stare *et al*., 2013), but Göbel *et al*. (2012) include agriculture and if food waste from Swedish primary production were to be included, it is likely that the Swedish value would be at a similar level.

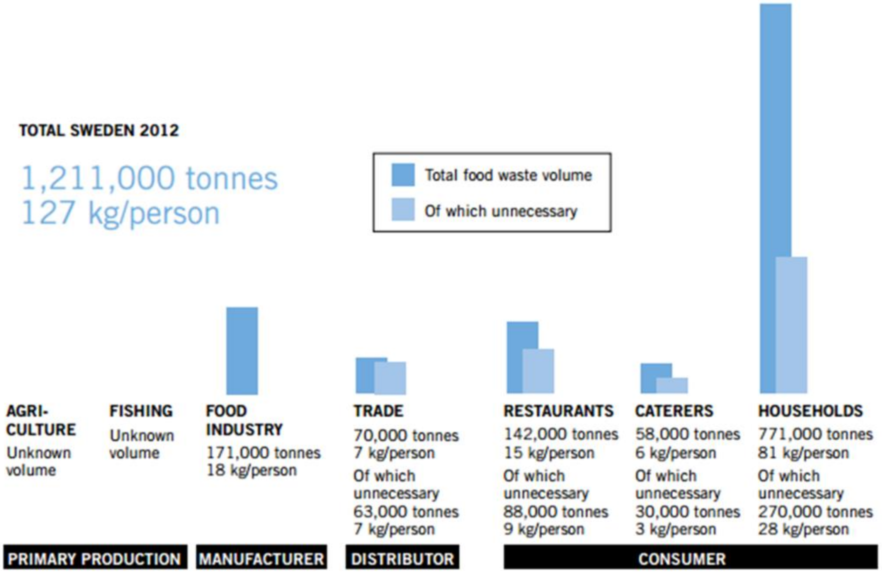

Figure 2. Estimated volumes of food waste generated in Sweden in 2012 (SEPA, 2013).

The retail sector of the food supply chain is not the largest contributor of food waste, but the amounts are still high and the share of unnecessary waste is also high (Figure 2), which makes it an important issue. Other aspects are that food waste becomes concentrated in a limited number of physical locations, making food rescue measures feasible. Supermarkets also represent an important link between producers and consumers, with potential influence over large parts of the food supply chain. This makes it possible for retailers to communicate with consumers in order to increase their environmental awareness and also to choose suppliers and producers that fulfil their corporate responsibility. Retailers are particularly important for the Swedish food supply chain, since the market is extremely concentrated and is completely dominated by just a few large companies (Eriksson, 2012). For example, the market share of the five largest food retailing companies in Sweden amounted to 94.7% in 2002, which was the highest in Europe, where the average level was 69.2% (Vander Stichele *et al.*, 2006). These five companies also own or control large parts of the distribution chain and, via private brands, some of the production.

3.3 Carbon footprint of food production and waste handling

Life cycle assessment (LCA) is a method for analysing the environmental impact of a product or service by analysing different aspects such as land use, water use, eutrophication, climate impact and acidification. Since many different aspects are included, a substantial review of environmental impact can be assessed. The problem is of course that it requires large reasearch resources to make a full LCA with many impact categories for a variety of products or services, with many geographical regions and production systems that need to be considered. Carbon footprint (CF) assessment provides a limited perspective, since only the global warming potential (GWP) is included. However, a less extensive assessment can instead allow analysis of a larger number of scenarios or a more extensive product range, using the same research resources.

A large number of studies on the GWP or CF of food products have been performed (Roy *et al.*, 2009; Röös, 2012). As pointed out by Röös (2013), the results vary widely between different food products, but also for a particular food product depending on factors such as production system and methodological choices in the assessment. However, one pattern which has emerged is that products of animal origin generally have a considerably larger CF than products of vegetable origin (EC, 2006), and that this footprint are generated already at farm level. Meat, particularly lamb and beef, has an exceptionally high CF, followed by cheese, due to the contribution of methane (CH_4) from enteric fermentation in ruminants. Meat from monogastric animals, such as pigs and poultry, has lower CF values than products from ruminants, but still higher than most foods of plant origin, due to the large amount of feed needed in livestock production and emissions from manure handling. Some fruit and vegetables can have a considerably high CF if produced in heated greenhouses, transported by air or produced in low-yielding systems (Stoessel *et al.*, 2012). For many food products, nitrous oxide (N_2O) emissions from soil also contribute significantly to the CF.

Losses in the food supply chain are seldom included in the CF of food products, possibly due to lack of data. If the wasted part were to be included, the CF of some food products could increase significantly, since surplus production is needed to cover both the fraction consumed and the fraction wasted. If food waste is managed properly, it could be used as a byproduct that can replace other virgin materials and thereby, to some extent, reduce the CF. However, according to Hanssen (2010), producing biogas from food waste only saves approximately 10% of the emissions generated during the production of surplus food, so the recovery of food waste can be considered a small part of the life cycle of food.

Even though waste management only can recover a small fraction of the resources invested in food production, it is still important to consider waste management due to the large quantity of waste generated. According to many review studies (*e.g.* Bernstad & la Cour Jansen, 2012; Laurent *et al*., 2013a; 2013b), the CF of food waste could be reduced by shifting from less favoured options in the EU waste hierarchy (EC, 2008) to higher priority options. According to Laurent *et al*. (2013a), the most common order in the waste hierarchy is landfilling as least favourable, followed by composting, thermal treatment and anaerobic digestion as the most favourable. However, there is great variation due to differences in local contexts, but also the use of different methodology to assess the different waste management systems (Bernstad & la Cour Jansen, 2012; Laurent *et al*., 2013a; 2013b).

3.4 The waste hierarchy

The EU waste hierarchy is set in the European Waste Framework Directive (WFD), which ranks waste prevention and management options in order of priority (EC, 2008). The WFD also obliges member states to encourage options that deliver the best overall environmental outcome from a life cycle perspective, even when this differs from the waste hierarchy. However, since the environmental outcome is not defined in the WFD, this goal can be achieved in many ways. Addressing GWP is one way to do so, but GWP alone offers only a limited perspective on the overall environmental outcome, although to some extent it can act as an indicator of other environmental impact categories (Röös *et al*., 2013).

Early versions of the waste hierarchy have been part of European policy since the 1970s (EC, 1975). While it has been developed and amended (EC, 2008), it still provides only very general guidelines for all waste, including the priority order from prevention, re-use and preparation for re-use, recycling, recovery and, last and least favourable, dumping in landfill. Guidelines relating specifically to food waste have therefore been devised. Examples of such systems are the Moerman ladder in the Netherlands (Dutch Ministry of Economic Affairs, Agriculture and Innovation, 2014), the Food Recovery Hierarchy in the United States (USEPA, 2015) and the Food Waste Pyramid in the United Kingdom (Feeding the 5000, 2014). All these systems prioritise prevention, since all other waste management options include downcycling and loss of the intended product. Despite the order of priority in the waste hierarchy, only a few studies measure waste prevention in the context of waste management (Laurent *et al.*, 2013a). This omission may be due to the methodical difficulties in measuring something that is not there (Zorpas & Lasaridi, 2013) or, as discussed by van Ewijk & Stegemann (2015), to prevention being fundamentally different from waste management.

The US Food Recovery Hierarchy, which is shown in Figure 3 (USEPA, 2015), agrees with the general principles of the EU waste hierarchy (EC, 2008), but has one important difference in that it separates the prevention stage into what can be seen as two sublevels. The more preferred sublevel is source reduction and the less preferred sublevel is feeding hungry people. This is important, since it implies that even though the food is eaten in the latter option, which corresponds to its intentional use, it is better to be proactive and reduce food production.

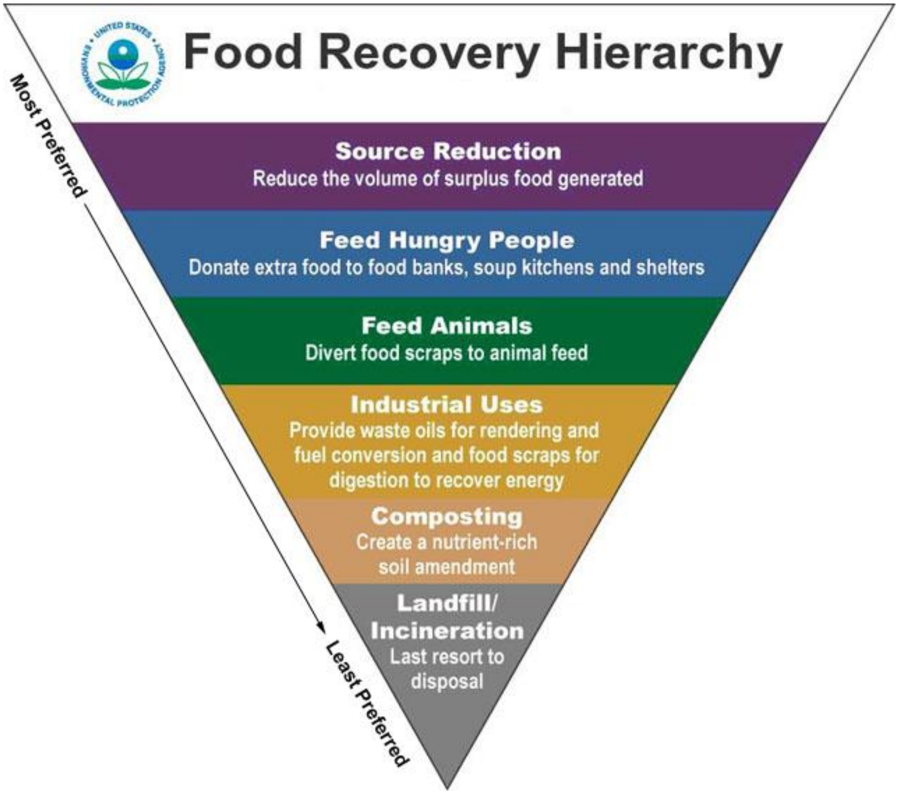

Figure 3. The Food Recovery Hierarchy developed by the USEPA (2015).

Feeding hungry people is also limited by the fact that food waste can only be donated to charity if it is surplus food still fit for human consumption (Papargyropoulou *et al.*, 2014). Since the food hygiene or biosecurity requirements increase at higher levels in the waste hierarchy, there is a decreasing likelihood that the whole waste flow will be suitable for the same type of waste management if using a more preferred method. This creates a need for more complex systems where part of a food waste flow is developed and used for higher priority waste treatments, while the rest is treated with a lower priority, more general method (Vandermeersch *et al.*, 2014).

3.5 Structuring waste reduction efforts

In organisations and companies, waste reduction is often sought by copying the best practice within the organisation or by taking inspiration from other successful examples of waste reduction measures (EC, 2010; Lagerberg Fogelberg *et al.*, 2011). Whether the suggested measures actually reduce the waste and by how much are seldom reported, and thus it is difficult to compare different measures and decide on the most efficient methods to reduce waste. Therefore, in this thesis a more analytical approach was adopted, based on the Deming cycle (also known as the plan-do-check-act methodology) used for environmental management systems in order to reduce waste (ISO, 2010). This strategy was suggested by Eriksson (2012) and involves:

1. Quantification of waste.
2. Analysis of causes.
3. Introduction of measures.
4. Evaluation of measures.

The steps to reducing waste involve describing the problem and the underlying reasons for risky behaviour, testing solutions and then evaluating how well the solutions actually reduce the problem and how much they cost.

3.5.1 Quantities

Retail food waste has been quantified in a few previous studies (Table 2). In all these studies, different system boundaries, methods and units have been used. In addition, different products have been studied, making comparisons difficult, although the results from the studies do not vary widely. The results indicate that retail food waste for different product groups is often in the range 0-10%. Many previous studies have focused on fresh fruit and vegetables

(FFV), which often give high percentage waste, *e.g.* 10% for the European retail distribution sector according to FAO (2011).

No previous publication states the percentage of waste originating from the retail sector in Sweden. However, if the wasted 70 000 tons per year reported by SEPA (2013) are divided by the 3.5 million tons per year delivered to Swedish supermarkets, approximated from Jensen *et al.* (2011b), these supermarkets waste approximately 2% of the mass delivered. This is well in line with the 1-2% waste reported for Finnish supermarkets (Katajajuuri *et al.*, 2014).

Table 2. *Brief review of studies in the literature quantifying food waste in supermarkets*

Reference	Country	Data collection method	Reference base	Product group	Relative waste (%)
Katajajuuri *et al.* (2014)	Finland	Interviews	Not specified	Retail sector	1-2
Göbel *et al.* (2012)	Germany	Analysis of national statistics	Delivered mass	Retail sector	1
Buzby *et al.* (2009)	USA	Supplier records	Supplier shipment data	Fruit Vegetables	8.4 - 10.7 8.4 - 10.3
Buzby & Hyman (2012)	USA	Analysis of national statistics	Food supply value	FFV	9
Beretta *et al.* (2013)	Switzerland	Estimate from store records	Volumes of sales	FFV	8 – 9
Fehr *et al.* (2002)	Brazil	Quantification at retailer	Delivered mass	FFV	8.8
Stensgård & Hanssen (2014)	Norway	Store records	Sales value	Fruit Vegetables	4.5 4.3
Lebersorger & Schneider (2014)	Austria	Store records	Sales in cost price	FFV	4.3
Mattsson & Williams (2015)	Sweden	Store records	Sold mass	FFV (only in-store waste)	1.9
Buzby & Hyman (2012)	USA	Analysis of national statistics	Food supply Value	Dairy products	9
Lebersorger & Schneider (2014)	Austria	Store records	Sales in cost price	Dairy products	1.3
Stensgård & Hanssen (2014)	Norway	Store records	Sales value	Milk products Cheese	0.8 0.9

3.5.2 Causes and risk factors

Food can be wasted for a large variety of reasons, which makes the food waste issue difficult to solve with one single solution. Common reasons for food being discarded in supermarkets are expired shelf-life or visual defects that make food unsellable (at least at full price). However, as pointed out by Lindbom *et al.* (2014), it is important to identify not just the reason for food being discarded but also the underlying root cause of the problem. However, such identification is problematic, since there are so many potential root causes of *e.g.* expired shelf-life, such as too short shelf-life, too large inflow of products, unexpected lack of demand, or a combination of all of these. Since it is very difficult to identify a single root cause, risk factors are used here since they better capture the multiplying effect when several risk factors are present and include factors not necessarily leading to food waste, but just increasing the risk of waste. Possible risk factors can be low demand, short shelf-life, unsuitable packaging or storage conditions and inappropriate handling by staff and customers.

In an extreme perspective, an inflow of food that is unbalanced with regard to the outflow required can even be assumed to be the only root cause of food waste. If so, all problems that prevent a supermarket from selling the food are risk factors. These risk factors can also have an effect on the inflow, since the supermarket will try to order just the right amount of all products, but anything that creates variation will make this forecast more difficult. Thus to summarise, if the forecast is just right there will be no waste and no empty shelves, but everything that introduces variation will make forecasting more difficult and increase the risk of food waste (or empty shelves).

There are several activities and problems introducing variation. One is increased product variety (Lindbom *et al.*, 2014), since having more different types of products decreases turnover for each and makes forecasting more difficult. On the other hand, providing a large variety of products also means freedom for customers, which supermarkets might use as a competitive advantage to differentiate them from their competitors. Since larger variety might thus be expected to increase profits, it might be something that the retailers are unwilling to alter, and waste is simply a part of the price they have to pay for the larger range of products sold.

Promotions have a similar effect on food waste since they temporarily shift the turnover of products and make forecasting more difficult. According to Hernant (2012), some promotions prompt the customer to buy the promoted product, but to reject other similar products as a consequence. Since forecasting of sales is more difficult when there are many aspects to consider, temporary shifts in sales can be difficult for retailers to predict accurately. This leads to a larger than necessary stock of not promoted products and, since the store must not run out of the promoted product, also a surplus of the promoted product. The result of the campaign is increased waste of the promoted product and also increased waste of other similar products. Added to the cost of the waste is the lack of profit that arises when the store sells products at a lower margin than usual. Thus promotions can really seem a waste of effort (Hernant, 2012), but they are unlikely to disappear since they are there to attract customers and thereby increase overall profits. Promotions can therefore be viewed as a marketing cost and waste as simply part of that cost.

In many cases the food waste does not appear in the same organisation that caused it. If customers decide to stop buying a certain product, this product is likely to end up as food waste if the supplier cannot stop its production fast enough or find an alternative market. If this change in purchasing behaviour is made by a single customer it might not affect the food logistics system at all, but when many customers unexpectedly change their behaviour the food supply chain simply cannot react fast enough to prevent overproduction and eventually food waste. A fast reaction from a customer group might also cause a chain reaction along the value chain that increases the effect and, in the end, creates large amounts of food waste in primary production. According to Taylor (2006), there are a number of actions in the supermarket that can lead to a “bullwhip effect”, where the amplitude of the customer reaction increases from retail to wholesale, from wholesale to industry and from industry to primary production and everyone along the chain increases/decreases production and increases/decreases stock in order to compensate for the customer reaction. Increased communication along the logistics chain so that primary producers get their signals directly from the end customers could be one way to deal with this problem. Another way to decrease the risk of a bullwhip effect could be by reducing the activities that increase variation. According to Taylor (2006), these activities include promotions, large numbers of products and/or actors in the logistics chain, and ordering and production in large batches with large stocks. Therefore the same risk factors for food waste can be problematic both within supermarkets and in other parts of the food supply chain.

Most types of waste and losses are unintentional, but since several risk factors are accepted as a normal part of any activity, waste must also be accepted as something natural. A common reason for accepting the presence of risk factors is that they are too expensive or too difficult to prevent. There can also be a conflict of interest between waste reduction and increased profit or public health, with waste reduction being likely to be a lower priority. To put this simply, there are a large number of problems causing food waste that are not interesting to solve because the potential benefits are believed to be less than the cost of change. On the other hand, there are also many problems that could easily be economically justified and therefore should be dealt with in order to reduce food waste (Eriksson & Strid, 2013). The problem is knowing which problems have low required management intensity (Garrone *et al.*, 2014), meaning that they are cheap and/or easy to solve. With this knowledge, a countermeasure to reduce risk factors can be designed so the potential savings can be compared with the expected cost of the intervention.

3.5.3 Measures

In order to reduce food waste in supermarkets, there is a need for measures that solve the basic problems which cause waste. Waste quantification and cause identification are often performed in order to design measures. These can be seen as necessary pre-studies in order to identify where to target a measure, but also to select the measures with the largest potential for reduction and/or the lowest cost.

Food waste reduction measures can be categorised in several different ways, but the main distinction is between prevention and valorisation measures. Prevention measures aim to reduce the production of food, while valorisation measures aim to create value from the waste occurring and thereby reduce the negative effect of the waste. Donation to charity can be considered a prevention measure, since the food is eaten by humans, but also a valorisation measure, since it handles the surplus food rather than reducing the production of food. Valorisation in this case can be considered in strictly monetary terms, as done by Eriksson & Strid (2013), who only considered measures that use the food for human consumption. Value in this case can have a wider meaning, *i.e.* including any byproduct that reduces the negative effects of the waste (Vandermeersch *et al.*, 2014), but it can also just apply to food (and uneatable parts of food) sent to animal feed, bio-material processing or other industrial uses (Östergren *et al.*, 2014). In their wider meaning, valorisation measures can include any waste management option that recovers nutrients, energy or byproducts from the food waste. It can also include waste management options that give rise to less emissions or less general problems then the worst option, *e.g.* landfill or even illegal dumping.

Most previous studies on waste management methods for food waste, or organic waste including food waste, describe and sometimes compare landfill, incineration, composting and anaerobic digestion (Bernstad & la Cour Jansen, 2012; Laurent *et al.*, 2013a; 2013b). However, all these options occur within the less prioritised part of the waste hierarchy defined by the European Waste Framework Directive (EC, 2008). Some studies also include animal feed in the comparison (*e.g.* Lee *et al.*, 2007; Menikpura *et al.*, 2013; Vandermeersch *et al.*, 2014), but none includes comparisons with the highest levels in the waste hierarchy, such as donation and prevention. However, some studies describe the environmental benefits of preventing food waste. For example, Gentil *et al.* (2011) concluded that there are significant benefits of reducing food waste, especially wasted meat, by 20% in a food waste stream. However, those authors do not specify how this reduction should be achieved, or the cost of doing so. Williams & Wikström (2011) & Williams *et al.* (2008) investigated whether waste reduction can justify the increased use of packaging material and found that it could do so for resource-consuming products such as cheese and beef. However, those studies did not specify how large the potential reduction could be if the packaging was redesigned. Another prevention study, by Salhofer *et al.* (2008), regarded prevention as being equal to donation, but did not quantify the actual potential in this measure. Moreover, Schneider (2013a) valued donated food by its emissions during production, instead of the produce that could be replaced. The lack of studies quantifying higher levels of the waste hierarchy with a method comparable to the lower levels makes it difficult to evaluate the actual environmental benefits of donation and prevention in relation to other waste management options. Without such an extended analysis, the life cycle perspective described in the WFD will not actually be considered when selecting waste management options.

Among the large number of publications reviewed by Laurent *et al.* (2013a; 2013b), a pattern emerged in studies comparing different waste management alternatives. The least favourable option was landfill, followed by composting and thermal treatment, and the most favourable was anaerobic digestion. However, not all studies fitted this pattern. Therefore Laurent *et al.* (2013a) concluded that local infrastructure is essential for the outcome, making it more difficult to generalise results.

Despite the order of priority in the waste hierarchy, only a few studies have measured waste prevention in the context of waste management (Laurent *et al.*, 2013a). This omission may be due to the methodical difficulties of measuring something that is not there (Zorpas & Lasaridi, 2013) or, as discussed by van Ewijk & Stegemann (2015), to prevention being fundamentally different from waste management. One of the differences that make it fundamentally different is that waste management options are carried out by professions handling waste management facilities, such as a municipal department, but prevention measures can only be handled by staff in the supermarket or by logistic departments in retail and wholesale companies. This means that supermarket staff have little influence over what happens with the food waste after it leaves the supermarket and that waste management professionals have little influence over what happens with the food before it becomes waste.

Prevention of food waste relates more to resource management than to waste management and therefore it is important to achieve source reduction, *i.e.* reduced production, and not just prevent the food entering the supermarket. However, there is no guarantee that the waste will not just move to an earlier stage in the food supply chain and sub-optimisations like this reduce the effect of the prevention measure. From an environmental perspective, it is not a solution to move the waste as a way to prevent it occurring, even though when waste occurs earlier in the food supply chain some sub-processes such as transportation, storage and packaging might still be avoided (Strid & Eriksson, 2014; Strid *et al.*, 2014). From an economic perspective, it might be enough to reduce the inflow of food into the supermarket, although the food will then be wasted at the supplier or producer, as long as the supermarket does not have to pay. Moreover, the producer may increase the price of the food supplied in order to cover the waste cost and if so, the supermarket will have to pay for the waste anyway.

Swedish supermarkets are likely to use the local infrastructure available for waste management, which means that if they do not prevent food waste or donate it to charity, they send it to incineration, composting or anaerobic digestion. Since it has been illegal to dump organic matter in landfill in Sweden since 2005 (Ministry of the Environment and Energy, 2001), it is very unlikely that any of the Swedish supermarket food waste is disposed of in this way. According to Jensen (2011a), 22% of the food wasted in Swedish supermarkets is managed with biological treatment, while the rest can be assumed to be incinerated for production of district heating.

4 Material and Methods

The work presented in this thesis is based on case studies performed in the context of six supermarkets located in Stockholm and Uppsala in Sweden. Paper I used the data to quantify wasted fruit and vegetables and Paper II quantified waste of organic food from the cheese, dairy, deli and meat departments and analysed causes of this waste. Through an extended literature review, Paper III added the perspective of CF associated with the wasted quantities. Paper IV combined the causes analysis in Paper II and the CF analysis of wasted food from Paper III with a literature review to examine shelf-life extension potential and energy consumption at reduced storage temperature. To extend this perspective, Paper V investigated different waste management options that could be used for the fractions of the food waste that cannot be prevented.

The six supermarkets investigated are owned, and were selected for the study, by the head office of Willy:s, which is a major actor on the Swedish low price retail market. The stores were selected within a specified region close to the university performing the research and to provide a representative view of the whole retail chain with regard to factors such as turnover, percentage waste and profit. Within these supermarkets, the fresh fruit and vegetables, dairy, cheese, meat and deli departments were selected for in-depth study, in consultation with the retail company, due to their large contribution to food waste and the expected high environmental impact of this waste. The bread department also makes a large waste contribution, but this is managed separately by the suppliers and was therefore not included in the quantification studies. Wasted bread is considered in Paper V, but using only assumptions regarding the wasted mass.

The material and methods used for data collection are described in detail in Åhnberg & Strid (2010), Eriksson & Strid (2011; 2013) and Eriksson (2012). In the study by Eriksson (2012), material flow analysis (MFA) was used as a method to investigate the incoming and outgoing flows of food within a group of supermarkets (Brunner & Rechberger, 2005). Variations on the MFA approach (including life cycle inventories) were used in Papers I-V in order to establish the mass of each type of food leaving the supermarkets either as any type of waste or as sold food. In Paper I the use of MFA was most extensive, since a full mass balance was performed for the waste in the FFV department. More extensive LCA was performed in Paper III regarding the CF from cradle to retail, in Paper IV regarding the cost and benefits of reducing waste through reduced storage temperature and in Paper V where different waste management options for the food waste were assessed (Figure 4).

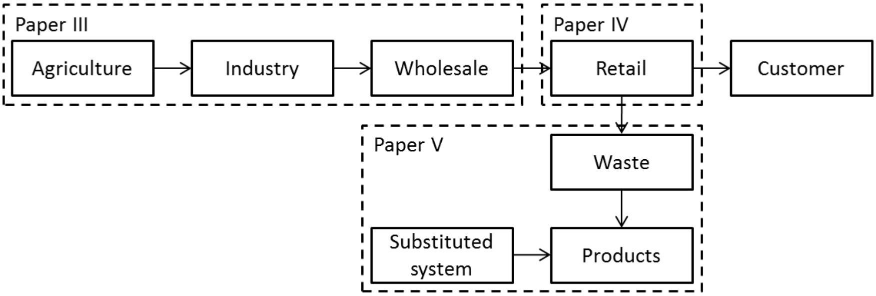

Figure 4. The food supply chain with the system perspective from each of the papers (III-V) using LCA as a method. Paper IV also relies heavily on results from Paper III that are not included in the diagram.

4.1 Classification and definition of food waste

The definition of food waste used in this thesis is that proposed by Östergren *et al.* (2014): “Food waste is any food, and inedible parts of food, removed from the food supply chain to be recovered or disposed of (including composted, crops ploughed in/not harvested, anaerobic digestion, bio-energy production, co-generation, incineration, disposal to sewer, landfill or discarded to sea)”. Since supermarkets sell food products that have not yet been separated into their edible and inedible parts, the waste consists of a mix of avoidable, possibly avoidable and unavoidable food waste (EC, 2010; WRAP, 2011). Since *e.g.* a banana is sold in the supermarket with the peel on, it is also wasted with peel and a categorisation like that suggested by EC (2010) and WRAP (2011) is only applicable at a stage in the FSC where the banana is consumed.

Food waste from supermarkets can be divided into several categories depending on system boundaries (Östergren *et al.*, 2014) but, as described in

Paper I, food waste (or retail food waste) was defined in this thesis as products discarded in the supermarkets studied, irrespective of whether they belonged to the supplier or the supermarket. This meant that losses of mass due to theft or evaporation were not considered food waste and are therefore included in a separate category (missing quantities) in Figure 5.

Pre-store waste consisted of items rejected by the supermarket at delivery due to non-compliance with quality requirements. This waste belongs to the supplier in accounting terms, since it is rejected by the supermarket, but is usually discarded at the supermarket. Pre-store waste is defined through documented complaints to suppliers, which according to the rules must be done within 24 hours of delivery. This waste is on rare occasions sent back to the supplier for control, but is still wasted.

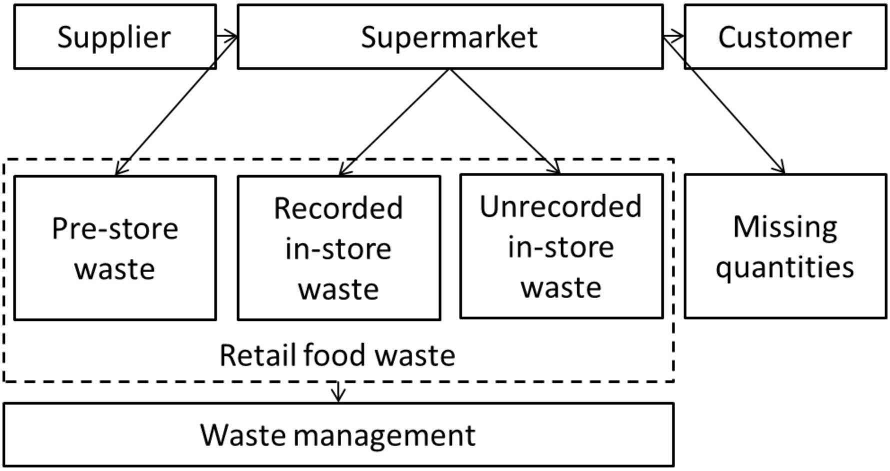

Figure 5. Flow chart with an overview of the waste categorisation used and the physical flow of food marked with arrows.

Recorded in-store waste was defined as food waste occurring after purchase from the supplier. This waste is sorted out and discarded by supermarkets when there is little or no possibility of selling the products. This could be due to exceeded best-before date or product deterioration for unpackaged fresh fruit and vegetables.

Unrecorded in-store waste consisted of food waste that was discarded but not recorded. This means that it had the potential to be either pre-store waste or recorded in-store waste if recorded in any of these categories. Unrecorded in-store waste originated from two sources: underestimated mass when recording unpackaged waste; and unrecorded of wasted items. The latter can occur in error or as a deliberate act, *e.g.* it is not cost-effective to record small amounts of waste.

The three food waste categories all contributed to fill up the waste containers of the supermarkets studied, but there was also a category of missing quantities. This was due to loss of mass between outgoing and ingoing flows, the two main reasons for which are believed to be theft and mass loss due to evaporation. Stolen food is considered not to be an environmental problem, since it is believed to be eaten. Evaporation losses are also not primarily food waste, since the food items are left, but with a higher dry matter content and smaller mass. However, when visible, this might act as a secondary effect, leading to losses of food in one of the waste categories.

4.2 Collection and analysis of store data

4.2.1 Data collection for recorded waste and rejections

Food that was sorted out and discarded was recorded as part of a daily routine normally performed by the stores and established years before this investigation (Åhnberg & Strid, 2010). This routine was not introduced by the author, only used in order to collect data. The routine starts with an inventory in the morning where products considered unsellable are sorted out. Products are considered unsellable if they have passed their best-before or use-by date. Since some FFV are sold without a date label, the sorting of these products is based on visual appearance and the unsellable limit is defined by each staff member based on whether they would buy the product themselves (Willy:s, 2010).

Products from the deli, meat, dairy and cheese departments are recorded directly with a mobile scanner connected to the company database and then discarded. Waste due to poor quality at delivery is economically reimbursed by the supplier if the member of staff presses a one-digit code on the mobile scanner to indicate whether the waste is charged to the supermarket, the main supplier (DAGAB) or other suppliers.

Discarded fruit and vegetables are placed in the storage room until the end of the shift, when the staff record the waste. Recording is often done by the team leader or other experienced member of staff using the mobile scanner for waste at the supermarket’s expense. Waste due to rejections is registered first on paper and then transferred to the website of the logistics company (SABA) delivering all fruit and vegetables to the supermarkets. Since all products are owned by Axfood when handled by SABA, the data on rejections are then transferred to a database within Axfood (Figure 6).

The records on wasted products are stored in the retail company database. Data on rejections are stored by DAGAB and Axfood and were provided in the form of weekly reports to the author.

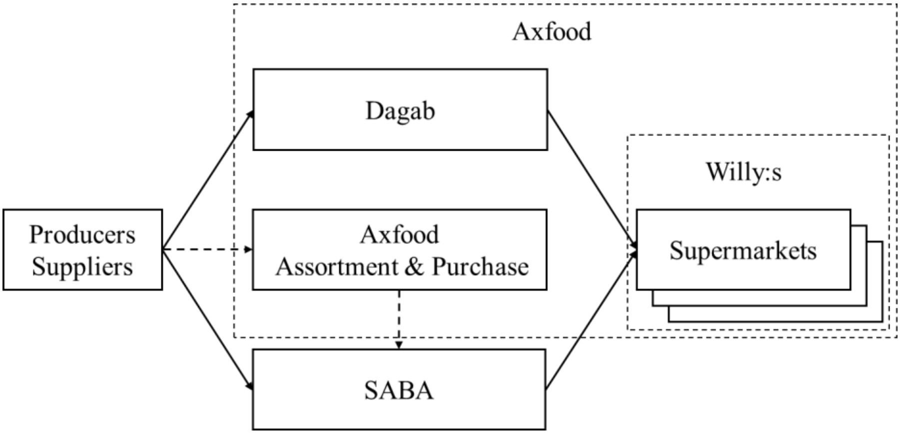

Figure 6. Flow chart with an overview of the companies involved in supplying food to the supermarkets investigated here.

4.2.2 Data collection for unrecorded waste

From observations and interviews with the staff, it became clear that the recording of wasted fruit and vegetables is not completely accurate. To quantify the missing part of the waste, a control measurement of the waste was performed. This method was closely related to the data collection methods used for household waste surveillance (Ventour, 2008; Andersson, 2012), with the distinction that the waste was not allowed to enter the waste container before recording. This manual recording of otherwise unrecorded waste was the only data collection process that could not harvest data from an existing system within the supermarkets.

The data collection was performed after the staff had recorded the waste, when instead of dumping the waste they left it together with printouts of the record. All fruit and vegetables in the pile were then measured on a set of scales to check the masses, which were compared with the masses recorded earlier.

During the first measurement of unrecorded waste, which lasted for two weeks, only differences between recorded and measured mass were quantified. It then became clear that some items were discarded without being recorded at all, and that some items were recorded without being found in the pile of waste, possibly discarded directly by mistake. Therefore a second quantification was performed during three days taking into account items discarded but not recorded, and *vice versa*. The absence of some items from the waste pile was tracked by asking the staff about every missing item to determine whether the item was expected to be in another location than the waste pile at that time, *e.g.* if some items were supposed to be discarded later or had already been discarded. All items that the staff did not expect to be in the pile were excluded from the study.

4.2.3 Data collection for delivered and sold mass

Sold products from all five departments investigated are recorded by the cashier at the pay point in the supermarket, or at a self-scanning pay point. These data are then stored in the financial records that the company is obliged to keep. Most products are recorded with the European Article Number (EAN) code on the packages, but some products, mostly fruit and vegetables sold unpackaged, are weighed at the pay point and identified by a four-digit price look-up (PLU) code typed in by the cashier. Mistakes in self-scanning or with the PLU codes are likely to create uncertainty in the data. The extent of this problem is unknown, but can be assumed to have no significant effect on the results presented in this thesis.

Delivered fruit and vegetables are recorded by the supplier as part of the financial records. These data were used in Paper I in order to calculate the missing quantities.

The supermarket departments studied are defined by the retail chain. The meat department sells fresh meat from terrestrial animals, mainly beef, pork and chicken, but also lamb and game meat. It also sells grilled chicken, raw sausages and some frozen meat. In the deli department, processed meat products such as sausages, meatballs and cold cuts, as well as black pudding and pâté, are sold. Besides dairy products such as milk, cream, butter and yoghurt, the dairy department also carries eggs and beverages based on fruit, vegetables or grain. The cheese department sells various cheeses, mainly hard or semi-hard cheese, soft cheese and cream cheese, but also tofu. The fruit and vegetable department sells a wide range of domestic and imported fresh produce.

All food products sold in the departments investigated can be aggregated at several levels. The lowest level of aggregation is the article level, where each article is defined by individual article number (EAN code). Some of these articles may have the same name, but different brands or package sizes. If the article code was changed over time without any change to the article, it was still considered as two separate articles in this thesis. The articles sold in the stores are grouped into categories defined by the supermarkets. These categories are grouped into departments, which in this thesis included the five departments cheese, dairy, deli, meat and fresh fruit and vegetables, all belonging to the division of perishable food. Since the store has no level for apples or oranges, an aggregation level between article and category, called product level, was created. The definition of products was not as robust as the other aggregation levels set by the supermarket, since there are several possible sublevels where the product level can be set and this level differs between different products. This can be exemplified by granny smith apples, which have more than one article number. In this thesis the product level was set to apple, but not to granny smith apple, which could also have been a possibility.

4.2.4 Analysis of waste data

Articles sold piecemeal were allocated a mass based on the mass stated on the package when this was possible. For articles sold without packaging (only FFV), the mass was set using the estimates used by the supplier for each article. (All masses stated as tons in this thesis refers to metric tons.)

Relative waste (RW) was calculated either in relation to the actual mass delivered (D) (Equation 1) or in relation to estimated mass delivered (Equation 2). The sum of sold products (S), pre-store waste (PW) and in-store waste (IW) was used as estimated mass delivered. The difference between the equations is the lack of a ‘missing goods’ term in Equation 2.

$$RW = \frac{W}{D} \qquad (1)$$

$$RW = \frac{W}{PW+IW+S} \qquad (2)$$

Equation 2 was mostly used in this thesis due to the lack of data on actual delivered mass of cheese, dairy, deli and meat. The exception was in Paper I, where Equation 1 was used since delivery data were available for the fresh fruit and vegetables department.

For unrecorded in-store waste, the difference between measured waste and recorded waste was calculated for each supermarket studied. The percentage difference was then used to calculate the difference for a whole year for each store, which gave the mass of unrecorded in-store waste.

4.2.5 Identification of systematic causes and risk factors of waste

The causes of food waste can be divided into systematic causes, which are often small but happen over a long time or on many occasions, and occasional causes, which are often the outcome of mistakes or rarely occurring events.

Three systematic causes or risk factors, short shelf-life, low turnover and large minimum order size, were analysed in more depth in Paper II. Shelf-life

(SL) was defined as the time between the production (or packing) date and the best-before date (or use-by date) or, in the case of eggs, from the production date to the last legal sale date (Persson, 2015). Turnover (T) was defined as the average number of items sold per week in weeks when the product was sold. Minimum order size (MOS) was defined as the minimum number of items a store can order on a single occasion. This was assumed to equal the wholesale pack size, which is the number of items delivered together in some kind of distribution package.

The waste risk factors were analysed in Paper II with the focus on organic products, which are often found to have high waste ratios. To test the hypothesis that low turnover, in combination with fluctuating demand, leads to wasted products, waste quantifications were supplemented with data on minimum order size and shelf-life for those deli products for which DAGAB had available data. The data on MOS (number of items) and SL (weeks) were combined with data on weekly turnover T (number of items per week) for each store to calculate the β-indicator (β), as shown in Equation 3.

$$\beta = \frac{T * SL}{MOS} \tag{3}$$

The β-indicator was used to explain part of the organic food waste in the dairy, cheese, deli and meat departments (Paper II), but since the data for both conventional and organic waste were used, the β-indicator can be applied to other products, especially those with low turnover. The β-indicator was developed in Paper II, but multiple linear regression (MLR) was also performed to confirm this method. The method of using MLR to obtain an equation describing how waste depends on T, SL and MOS was further developed in Paper IV, where it was used to simulate the outcome of prolonged shelf-life.

To establish the connection between reduced food waste and extended shelf-life, the model first presented in Eriksson (2012) and further developed in Eriksson & Strid (2013), Paper II, Björkman (2015) and Persson (2015) was used. This model employs multiple linear regression to provide an equation describing how the relative waste depends on T (sold items per week), SL (days) and MOS (number of items) from products where data on all parameters are available. In the MLR, the analysis was limited to only include food items with a shelf-life shorter than 85 days. The result was based on 984 articles consisting of 92 cheese articles, 258 dairy articles, 333 deli articles and 311 meat articles and Equation 4 were created from the MLR results, with an adjusted R^2 value of 0.666. The reduction in relative waste depending on increased shelf-life was calculated with Equation 4 and then applied to the recorded waste of each product in Paper IV.

$$\mathrm{Log(RW)} = 0.351 - 0.909 * Log(T) - 0.888 * Log(SL) + 0.156 * Log(MOS) \quad (4)$$

4.3 Carbon footprint of processes related to food waste

Life cycle assessment (LCA) (ISO, 2006a; 2006b) was used to calculate the global warming potential (GWP) associated with cradle to retail emissions in Paper III, emissions related to cold storage in Paper IV and different waste management options in Paper V. The functional unit used was always 1 kg of food, but due to the different contexts both production or prevention of 1 kg food delivered to the supermarket (Papers III and IV) and removal of 1 kg food (waste) from supermarket (Paper V) were used.

In LCA, emissions relating to waste are normally allocated to the product or service assessed. Therefore food waste cannot have a carbon footprint (CF) by itself, but just increases the CF of the consumed product. The food waste CF used in this thesis should therefore be interpreted as the CF of the food before it became waste, even though waste was not the intended product. From this, it follows that if this waste were to be avoided, the life cycle emissions of that specific product would also be avoided.

4.3.1 Carbon footprint associated with cradle to retail emissions

In all papers, CF was used synonymously with GWP_{100}. The CF was expressed in terms of carbon dioxide equivalents (CO_2e). The CO_2, N_2O and CH_4 emissions were included, where the GWP of N_2O and CH_4 was expressed relative to CO_2 according to the IPCC values (Solomon *et al.*, 2007).

In order to analyse the carbon footprint pattern of retail food waste, the CF of cradle to retail was calculated for different food products. Waste management of the food waste was not included, due to the low impact described in Nilsson (2012) and Paper V. The waste carbon footprint was defined as the specific CF value of a product, comprising emissions associated with the production and distribution up to delivery to the supermarket, multiplied by the total mass that was wasted in the stores (including pre-store waste) of the respective product. The specific CF values were determined based on existing literature, but the literature values were modified regarding transportation in order to better fit the distance from the actual country of origin to the supermarket located in Stockholm, as described in Scholz (2013).

The CF from cradle up to delivery to the retailer of all products was calculated based on information from the literature. These CF values and the literature consulted are listed in the appendix to Paper III. When more than one study on a specific product existed, the study that best represented the product at the store in terms of country of origin and production method and which used most current data was selected. Where the scope of the available literature did not exactly fit the purpose of the present study, assumptions or calculations were made as described in more detail in Paper III. In general, the most commonly included emissions associated with primary production, as well as emissions caused by processing and transportation up to the retailer, were considered. Potential emissions from land use change were not included. Emissions associated with store operations and packaging were also not included, since data availability was not sufficient and their impact was considered to be relatively low (Cederberg *et al.*, 2009; Stoessel *et al.*, 2012).

4.3.1 Carbon footprint associated with waste management options

In Paper V, five food products with different properties were selected to represent different waste streams that could be separated in the supermarkets. For each of the food products, a waste management scenario was applied and the CF associated with the management and substituted systems were calculated. The scenarios used were landfill, incineration, composting, anaerobic digestion, animal feed and donation, since they all represent possible ways to treat food waste locally with existing infrastructure. The first five waste management options have been described in several studies (Laurent *et al.*, 2013a) and the methodology is therefore well used. However, to the best of my knowledge the same methodology with system expansion has not previously been applied to food donation, with the exception of Eriksson &Strid (2013).

In the system expansion, the donated food replaced other food products that would otherwise have been bought by the charity and consumed by people in need. There is a wide variety of food items that could be replaced by donated products, but the same assumption as made by Eriksson & Strid (2013) was used, *i.e.* that all donated food replaced bread based on energy content. The reason why bread was selected as a substituted product is because it is one of the cheapest types of food that can be bought in Sweden with regard to energy content, and because it does not require preparation, unlike other cheap and energy-rich products such as pasta and potatoes.

4.4 Waste prevention and valorisation framework

In this remainder of this thesis, the framework presented in Figure 7 is used to describe how different waste management and prevention options relate to food waste and to each other. This framework is inspired by Papargyropoulou *et al.* (2014), Garrone *et al.* (2014), Östergren *et al.* (2014) and Eriksson & Strid (2013), but focuses only on the supermarket perspective. Due to supermarket specialisation, no distinction is made between avoidable and unavoidable food waste, since these are not separated until the consumer stage.

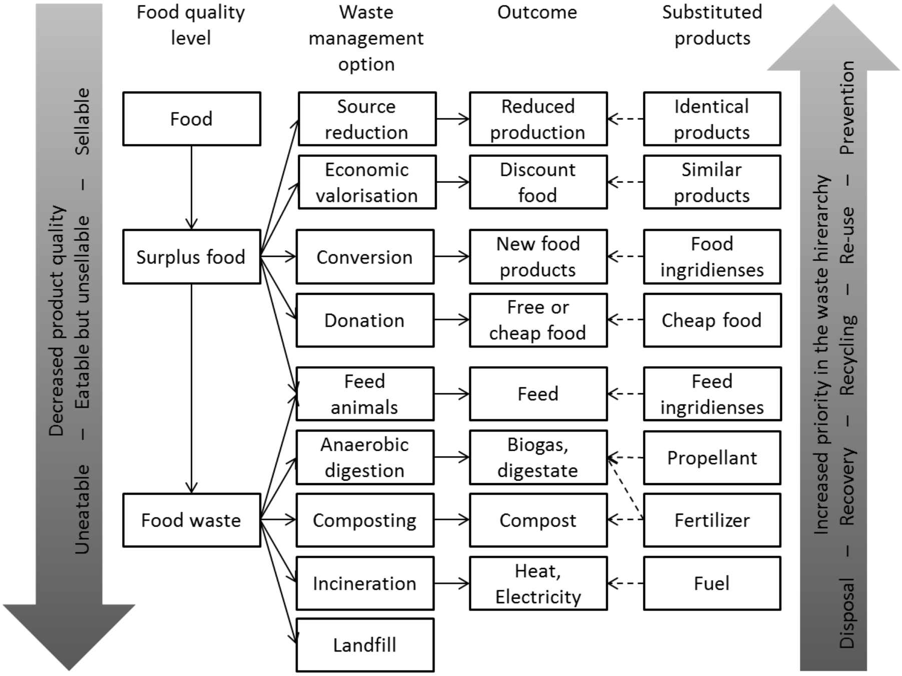

Figure 7. A waste management framework inspired by Papargyropoulou *et al.* (2014), Garrone *et al.* (2014), Östergren *et al.* (2014), Eriksson & Strid (2013) and findings within this thesis.

The concept of waste prevention differs depending on the perspective. From an environmental perspective, waste is prevented as long the food is never produced or used for its intended purpose, *i.e.* eaten by humans. From an economic perspective, it would be a waste to sell the food at a reduced price, since that is a loss of money. With this logic, the measure of cutting the price by 50% on the day before the best-before day may prevent food from being wasted, but still wastes some of the value of the product. However, since a price reduction also means that half the value is saved and since this thesis applied an environmental perspective, this type of measure was categorised as prevention through economic valorisation (Figure 7), since the food is sold through normal channels with a price reduction in order to save some of the economic value and possibly the whole environmental value.

In Figure 7 there are a few important trends that follow the order of priority in the EU waste hierarchy. First, the less prioritised measures are all general and do not require food waste with high levels of product quality, biosecurity, separation or storage conditions. Therefore these options are cheap and general, but have an outcome with much lower economic value than the original food products. In order to prevent food from being wasted (*i.e.* using it for human consumption), there are high hygiene requirements that need to be met, which makes separation and proper storage important. These options therefore need more effort from the supermarket, but in return provide a more valuable outcome. The problem is that the outcome of most waste management options is profitable for society (SEPA, 2011, 2012), but not necessarily for the supermarket.

5 Results

This results chapter is structured into three sections describing quantities, risk factors and measures. The first section mainly presents results from Papers I-III, while data for the years not included in these papers are presented in Appendix I-IV, including department data, category data, product data and article data. The second section describes a few problems causing food waste which are mainly covered in Papers II and IV. In the third section, different measures covered in Papers IV and V that reduce waste or reduce the carbon footprint of food waste are described.

5.1 Quantities

5.1.1 Quantities of wasted perishable food

During 2010 to 2014, a total of 2.4 kton of food waste was recorded in the five departments studied in the six selected supermarkets. The majority (84%, 2.0 kton) of the recorded mass was wasted in the fresh fruit and vegetables department and 77% or 1.6 kton of this was recorded as pre-store waste.

A summary of waste from the different supermarket departments during three years (2010-2012) is shown in Figure 8. Fruit and vegetables had a dominant position when the mass of waste was considered, contributed 86% of the waste, but only 72% of the cost of the waste and 48% of the carbon footprint produced in vain when wasting the food. The meat department displayed the opposite pattern to the FFV department, since meat only contributed 4% of the wasted mass, but 12% of the cost of the waste and 30% of the wasted CF. The deli and cheese departments followed the same trend as the meat department, but on a slightly smaller scale.

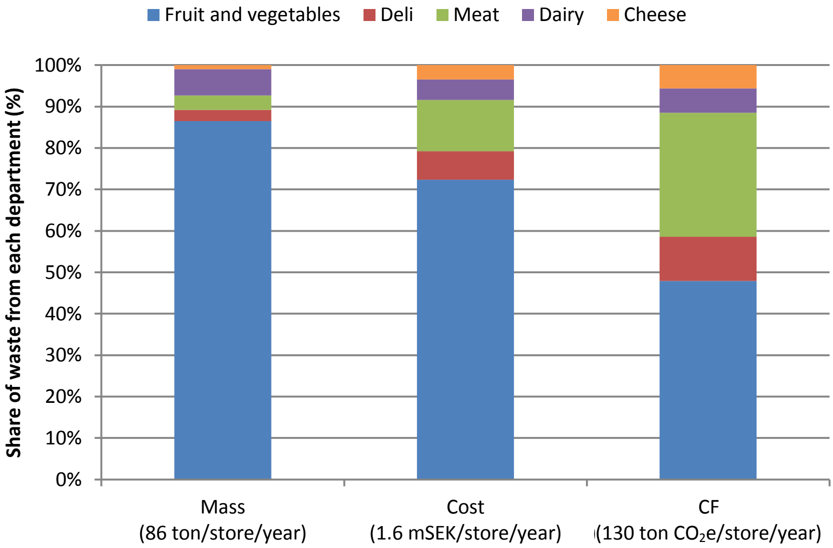

Figure 8. Total waste of perishable products from different departments in the six supermarkets studied during five years, quantified in terms of mass, purchase cost to the supermarket and carbon footprint (CF) associated with the lifecycle from cradle to retail for the wasted products.

In order to find hotspots in the waste data, it is not only whole departments that need to be investigated, but also the actual products within these departments. Paper I showed that the products making the largest contribution to FFV in-store waste mass were everyday fruit and vegetables, which are sold in large quantities, and not exotic fruits, which have higher percentage waste. For organic deli products, the largest waste contribution also came from products sold in large quantities, *e.g.* meatballs and Falun sausage (Paper II). Since Paper I only shows in-store waste during 2010 in the analysis of wasted products and Paper II only organic products, Appendices II-IV present data on the most wasted categories, products and articles.

For each of the five departments, a few articles represented a large share of the total wasted mass. The most extreme was the dairy department, where five products contributed almost half (47%) of that department's waste. In the other departments, the top five most wasted products contributed between 34% and 41% of the waste within each department. In terms of the carbon footprint, the concentration of waste from a few products differed and for some departments was even higher. In the FFV department, tomatoes, bananas and lettuce made a combined contribution of 36% to the waste carbon footprint. In the meat department, minced beef contributed 17% of the carbon footprint associated with that department's waste (Appendix III).

Since food waste can be quantified in different units, it is important to set the goals for waste reduction using units that actually measure what is intended to be achieved. Figure 9 exemplifies this issue when comparing the five supermarket departments investigated in terms of wasted mass and wasted carbon footprint. In comparison with 2010, the waste increased by 12% in 2011 in terms of mass, but decreased by 5% in terms of wasted CF. This was due to increased FFV waste and decreased waste of mainly meat. The trend of both increasing and decreasing waste continued to 2013, when the waste in the FFV department also started to decrease. This led to a total decrease in food waste, both in terms of mass and carbon footprint, from 2010 to 2014 by 21% and 26% measured in mass and carbon footprint, respectively (Figure 9).

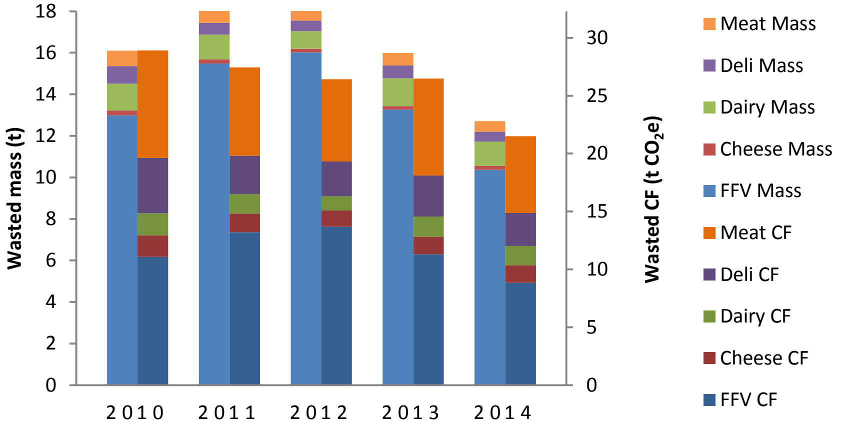

Figure 9. Total waste per year from different departments in the six supermarkets studied during five years, quantified in terms of mass and carbon footprint (CF) associated with the lifecycle from cradle to retail for the wasted products. The scale is set so the bars for 2010 are equally high in the diagram.

It is not only the use of different units that complicates food waste quantification. The waste is often set in relation to something else in order to make the results comparable between *e.g.* supermarkets of different sizes. When the waste in the present case was related to estimated delivered mass (Equation 2), it is clear that the main flow of delivered and sold food was important. Since the sold mass in the six supermarkets studied decreased by 12% from 2010 to 2014, the relative waste presented in Figure 10 gives a slightly different result compared with the absolute waste in Figure 9. When the waste was related to the sum of sold and wasted mass in all five departments, the relative wasted mass showed its peak value in 2012, while the relative wasted CF peaked in 2013. It is also clear that the trend of reduced wasted CF in 2010-2013 followed the reduced sold CF, and in relative terms therefore did not decrease (Figure 10).

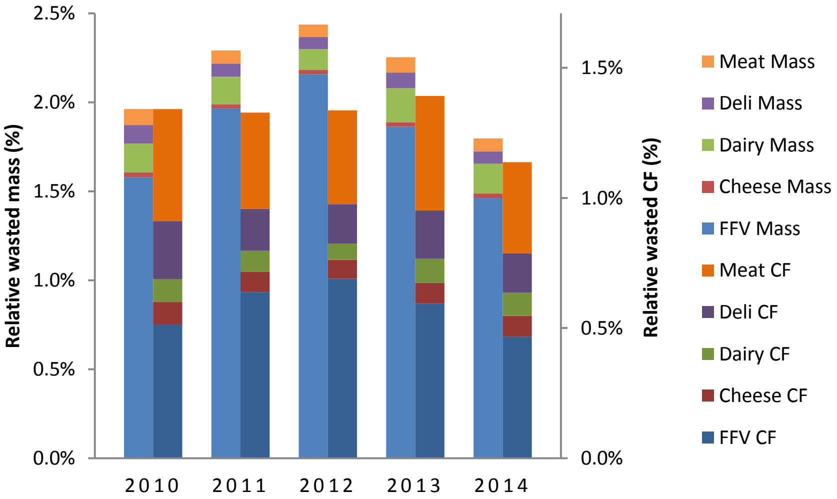

Figure 10. Total waste related to estimated deliveries per year from the different departments in the six supermarkets studied during five years, quantified in terms of mass and carbon footprint (CF) associated with the lifecycle from cradle to retail for the wasted products. The scale is set so that the bars for 2010 are equally high in the diagram.

Apart from variations due to the use of different units and absolute/relative numbers, there are also natural variations over time. In Figure 11 this is illustrated by showing the weekly average relative waste for each store during the whole study period. The highest weekly relative waste rate in a single supermarket was 7.3% and the lowest 0.5%. Since there are only a few high waste peaks in Figure 11, a long quantification period can be used to reduce the influence of these peaks. If waste is quantified during a short period, it might be heavily affected by an occasional high peak. If the waste is quantified for a less aggregated level than a whole supermarket, the variation between high and low values will increase.

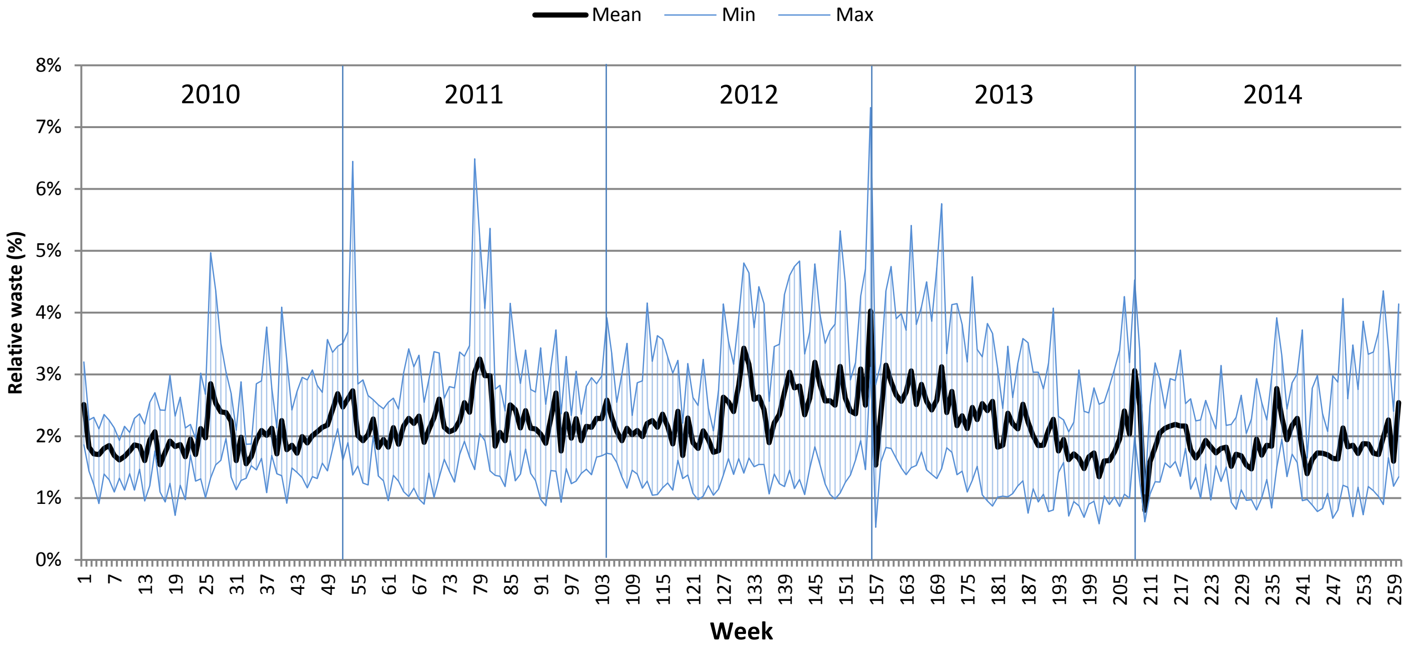

Figure 11. Mean, maximum and minimum values of the weekly relative waste in the six supermarkets studied during 2010-2014.

5.1.2 Mass balance of fresh fruit and vegetables

In Paper I, a mass flow analysis was performed to create a mass balance of fruit and vegetables in the six supermarkets, where 94.6% of the delivered mass was sold and the rest was distributed over the three categories of waste (4.3%) and missing quantities (1.1%). Missing quantities were calculated simply to achieve a balance between the inflow and outflow of food.

A similar mass flow analysis was performed with data for the following years (Table 3) with a maximum of pre-store waste during 2012, the same year as missing quantities reached the maximum. It is worth noting that the year with the highest pre-store waste (2012) also had the lowest in-store waste, while the year with the lowest pre-store waste (2014) had the highest in-store waste. Since the unsold mass was also lowest during 2014, it appears that the larger the share of in-store waste, the less total waste there is.

Table 3. *Results of mass flow analysis of fruit and vegetables in all six supermarkets studied during all five years. 'Unsold mass' corresponds to delivered mass minus sold mass; 'Recorded waste' corresponds to recorded pre-store and in-store waste*

Year	Delivered mass (%)	Pre-store waste (%)	In-store waste (%)	Sold mass (%)	Missing quantities and unrecorded waste (%)	Unsold mass (%)	Recorded waste (%)
2010	100	3.0	1.0	94.6	1.4	5.4	4.0
2011	100	4.2	0.9	94.1	0.8	5.9	5.1
2012	100	4.6	0.9	92.7	1.7	7.3	5.5
2013	100	3.6	1.2	94.1	1.1	5.9	4.8
2014	100	2.5	1.3	95.1	1.1	4.9	3.8
All	100	3.6	1.1	94.0	1.3	6.0	4.7

The missing quantities can be explained by theft or weight loss due to evaporation and this problem was in line with the in-store waste (1.3% compared with 1.1%). However, the small yearly variation seems to be a coincidence when looking at the same data divided by supermarket (Figure 12). Here the variation was larger and two supermarkets even showed negative missing quantities, which makes the theft and evaporation explanation more problematic. Store 3 stands out, with negative missing quantities during three of the five years, reducing the unsold mass to a lower level than recorded waste. Store 2 stands out with negative missing quantities that equal the recorded waste during 2012, meaning that 100% of the delivered mass was sold, according to the records on delivered and sold products.

The other supermarkets investigated had no negative missing quantities. Instead, they had large masses in this category, with a maximum in supermarket 6 during 2011 of 5.7% of delivered mass, which was higher than the sum of in-store and pre-store waste (5.2%). This high loss of mass also resulted in the largest difference between delivered and sold products, where only 89.1% was sold (Figure 12).

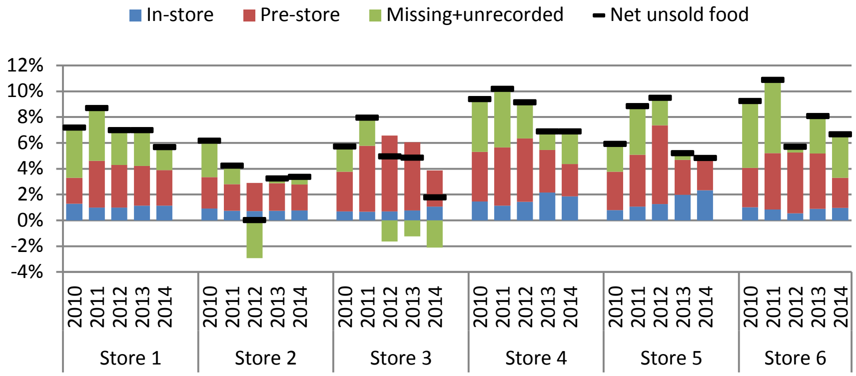

Figure 12. Results of mass flow analysis of fruit and vegetables for each of the six supermarkets studied during each of the five years investigated. The level of net unsold mass corresponds to the difference between sold and delivered mass.

5.2 Risk factors for food waste and causes of discarding food

Analysis of causes and risk factors for food waste in supermarkets is important in order to progress from identifying flows of waste to actually reducing these by introducing measures. Often these measures solve some kind of problem that has been causing waste or limit the potential effect of risk factors. Expired shelf-life is one reason for discarding food and short shelf-life could therefore be considered a risk factor for food waste. Short shelf-life was analysed in Paper II to find out if the time span between packing date and best-before date could explain the greater waste of organic products in comparison with conventional products. Since shelf-life did not differ between organic and conventional products, Paper II did not find short shelf-life to be a cause of food waste. However, a plot of the logarithm of shelf-life against the logarithm of relative waste (relative to the sum of wasted and sold mass) and absolute waste revealed a trend for increasing waste as shelf-life decreased (Figure 13). Nevertheless, the curve fit was far from perfect and therefore other risk factors must also influence the level of food waste.

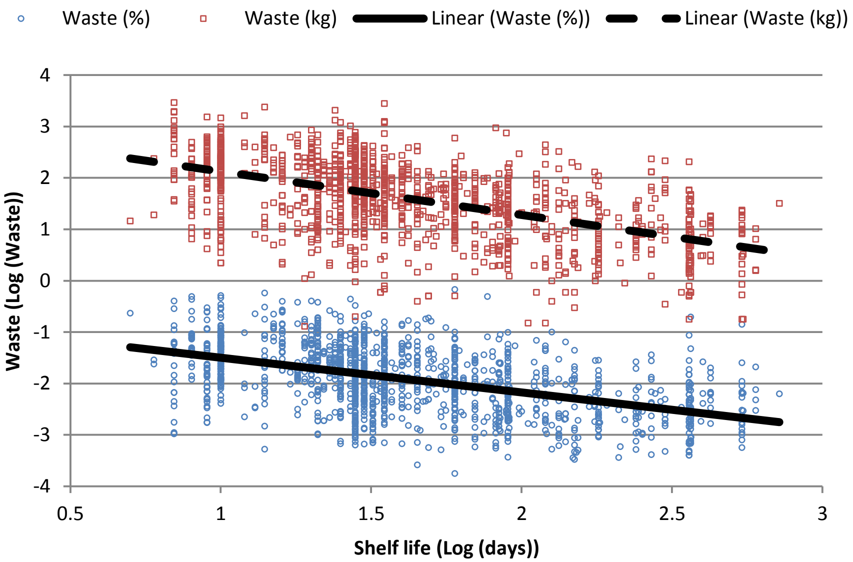

Figure 13. Logarithm of shelf-life is plotted against logarithm of relative waste (red symbols) and absolute waste (blue symbols), with a linear trend line added to each plot.

In Paper II, low turnover was also investigated as a risk factor to explain the high relative waste of organic products. In Figure 14, the logarithm of turnover is plotted against the logarithm of relative waste in order to identify its potential to cause food waste in comparison with the shelf-life factor. The trend visible in the diagram and the R^2 values of the linear fit both indicate that low turnover to a higher extent than short shelf-life caused food waste. However, the analysis is not complete, since low turnover could also be seen as a risk factor rather than the only root cause, which means that stocking too many products will produce waste since they might not all be sold before the end of the shelf-life, but the effect of overstocking will be even worse if the turnover is very low. Figure 14 also illustrates that the waste in absolute terms increases with increased turnover, simply because larger volumes are handled, but at the same time the relative waste decreases with larger turnover.

Since the minimum order size (MOS) is one parameter influencing the inflow of products, it was also analysed to see how it corresponded to relative waste. It was found that MOS was corresponded even less to relative waste than turnover and shelf-life (Figure 15).

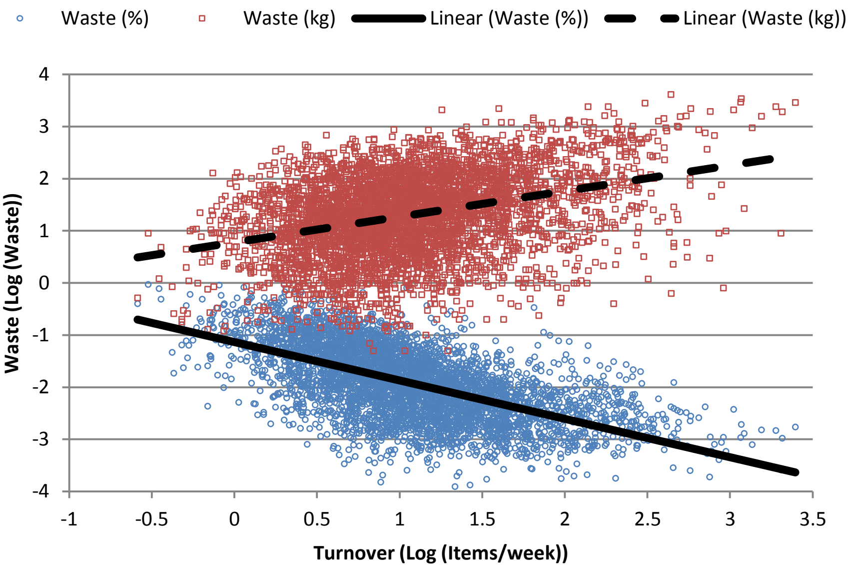

Figure 14. Logarithm of turnover plotted against logarithm of relative waste (red symbols) and absolute waste (blue symbols), and a linear trend line added to each plot.

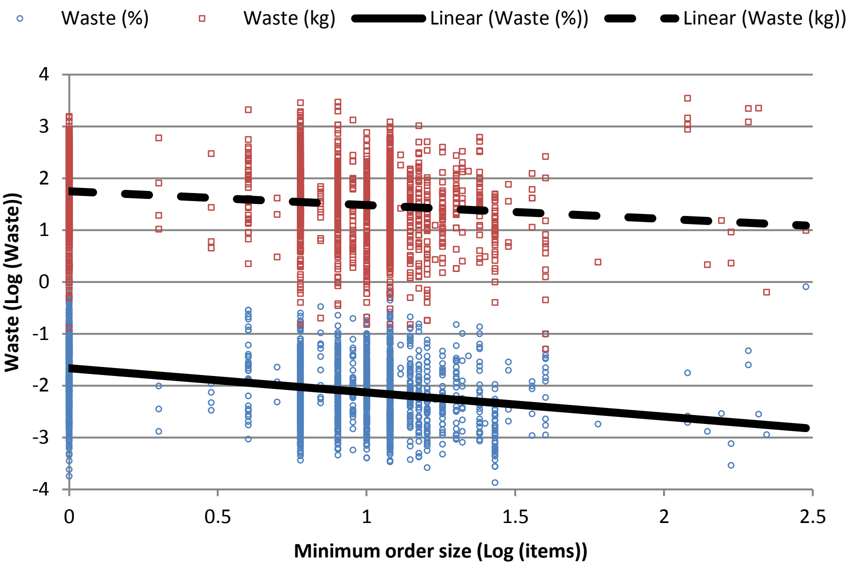

Figure 15. Logarithm of minimum order size plotted against logarithm of relative waste (red symbols) and absolute waste (blue symbols), with a linear trend line added to each plot.

In Paper II, both large MOS and short SL were found to be risk factors for food waste, but only turnover was found to differ between organic and conventional products. Therefore low turnover is a risk factor explaining why organic food has higher relative waste than conventional products. The fact that food is organic was not found to be a risk factor, although higher production costs can have an effect on the sell price and thereby the turnover.

5.3 Measures

In order to reduce food waste, there is a need for waste reduction measures. Potential target areas for these measures are the largest problems found in waste quantification, if these problems are caused by issues that can be dealt with. The basis used for categorisation of measures was presented in the introduction section of this thesis. The measures presented in this sub-section focus on the prevention measures presented in Paper IV and the valorisation measures presented in Paper V. Following this, these two fundamentally different ways of dealing with food waste, source reduction and waste management, are compared.

5.3.1 Prevention measures

The most efficient way of completely preventing food waste from occurring is of course to stop overproducing food and thereby potentially cause a lack of supply, but for obvious reasons this is not desirable. Instead, measures must both reduce waste and not jeopardise food security, which makes achieving complete prevention of food waste less likely. Therefore it might be more correct to talk about waste reduction rather than waste prevention, since waste is unlikely to completely disappear without radical changes in the food system. Some of the waste at the end of the food supply chain can still be prevented, however, thereby reducing the need for production. Just reducing the need for food production does not mean that food production will actually be reduced, but in all calculations of waste reduction benefits presented below this source reduction was assumed to take place.

In Paper IV, food waste was reduced by prolonging shelf-life through reducing the storage temperature for chilled products. Prolongation of shelf-life has the potential to lead to reduced waste, but also to increased energy use. The net effect of reducing storage temperature was calculated by deducting the cost of increased electricity use from the potential savings from reduced food waste. This gave a value for each supermarket department showing whether a reduction in temperature was justified from a reduced waste perspective.

If the storage temperature used for cheese, deli and dairy products were to be decreased from 8°C to 5°C, the waste associated with these products would potentially decrease by 15%, from 7.8 to 6.7 ton/store/year. The corresponding reduction for these products if the temperature were to be reduced from 8°C to 4°C and 2°C would be 18% and 25%, respectively. For the supermarket's meat department, a reduction in storage temperature from 4°C to 2°C would potentially lead to a 19% reduction in mass of wasted meat. Taking each supermarket department separately, the reduction potential would be in the range 9-30% (Figure 16), with the highest reduction potential at the lowest storage temperature in each department.

The largest net saving of carbon footprint was found in the meat department, where the potential savings from waste reduction were larger than the increased emissions related to reducing the storage temperature. This was due to the comparatively high level of waste, but also to the high CF per unit mass, which makes the need for cooling low and the potential waste reduction high. The dairy department was the opposite to the meat department, with a net cost of reducing storage temperature. This was due to the already low waste in the dairy department, but also the large quantities of water in dairy products that would be need to be chilled to reduce the storage temperature (Figure 17).

The deli and the cheese department can be described as intermediate between dairy and meat, with a moderate carbon footprint, price per kg, turnover and level of waste. The cheese department showed a trend for decreased net savings when the temperature decreased and the shelf-life was prolonged. In the deli department, the increased energy costs equalled the reduced emissions associated with food waste, so the measure of reduced storage temperature gave no net saving, just a shift from food-related emissions to energy-related emissions.

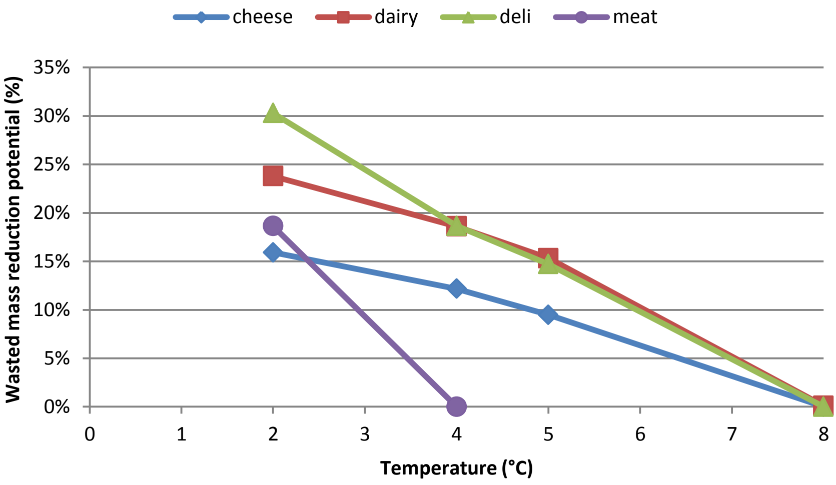

Figure 16. Potential wasted mass reduction (%) for different perishable food departments at different storage temperatures.

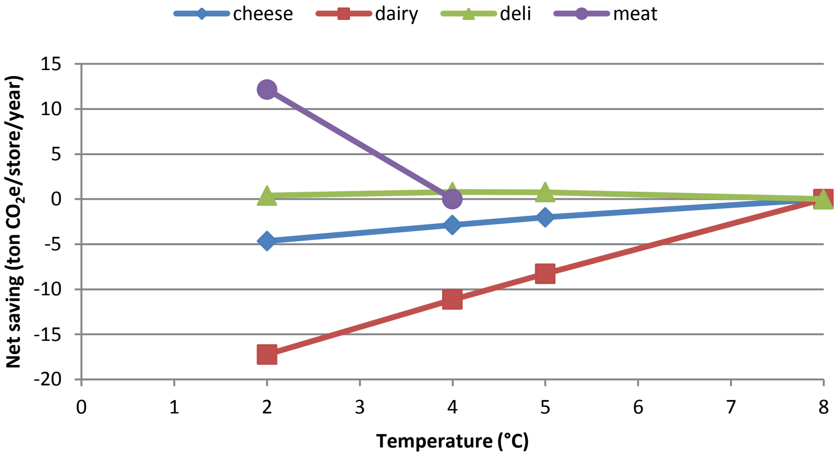

Figure 17. Net effect of reduced storage temperature in different supermarket departments considering the benefits, in terms of carbon footprint, of reduced waste and the cost of increased energy demand.

5.3.2 Valorisation measures

When food waste cannot be prevented, there are several different options available to manage the waste. In Paper V, six scenarios with differing priority in the waste hierarchy were evaluated. The results showed a trend for decreasing levels of carbon footprint with higher priority levels in the food waste hierarchy (Figure 18). For all five food products investigated, landfill was the option with the highest carbon footprint. At the other end of the scale, donation and anaerobic digestion were the alternatives with the lowest carbon footprint from the five food products. Donation was the alternative with the lowest emissions for grilled chicken and bread (even though incineration proved the lowest emissions for bread), but for bananas, lettuce and beef anaerobic digestion generated the lowest emissions.

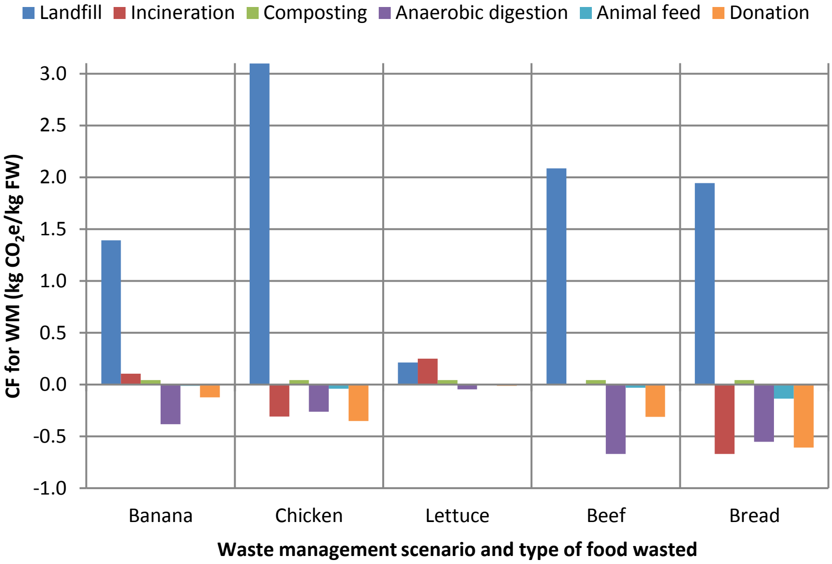

Figure 18. Carbon footprint (CF) of each waste management (WM) scenario and food product investigated in Paper V.

The other scenarios did not fully agree with the waste hierarchy. Incineration was a good option for dry food like bread and grilled chicken, but a poor option for the wetter lettuce and bananas, for which composting provided a better alternative (Figure 18). Similarly, anaerobic digestion was a better alternative than animal feed, for some products better than donation. According to these scenarios the priority order applied to bananas, grilled chicken, iceberg lettuce, beef and bread should therefore be anaerobic digestion, donation, animal feed, incineration, composting and, the least favourable alternative, landfill, when solely considering carbon footprint and general options. When considering specific options for specific food products, incineration with energy recovery is a favourable alternative for dry foodstuffs.

Different foodstuffs have different features that make them more or less suitable for different waste management scenarios. Bananas consist of a fairly large proportion of peel that was sorted out in the donation scenario, which meant that a lot of the wasted mass could not be used to replace bread. In the other scenarios, however, the banana peel was managed the same way as the rest of the banana and therefore only the donation scenario was affected. Since the chicken was grilled it was much dryer than beef, which made the energy content per unit mass higher and the water content lower. Grilled chicken was therefore much better to incinerate than beef, but for the same reason it gave rise to more methane in the landfill scenario. Grilled chicken produced less methane in the anaerobic digestion scenario, because the product included the whole carcass with bones. Bones were assumed either to be sorted out in the pre-treatment or simply not to produce any methane due to the short retention time in the biogas reactor. The bones were also considered not to be eaten in either the donation or animal feed scenario, which reduced the outcome from the chicken in these scenarios.

Lettuce has a low energy content and a high water content, which is why lettuce could be treated in any of the scenarios investigated without large differences in outcome. Bread was the opposite, with high energy content and low water content. Because of its energy carrying capacity, bread was useful for incineration, anaerobic digestion, animal feed and donation. However, its biogas potential was not as high as for meat products like beef and chicken, which resulted in less methane production in the landfill scenario and anaerobic digestion scenario. The energy content per unit dry matter was also higher in chicken and beef, due to a higher fat content.

5.3.3 Comparison of valorisation and prevention measures

Placing the results from Paper IV into the context of Paper V allowed comparison of all stages in the waste hierarchy. Figure 19 shows the outcome using all wasted beef products as an example. The combined waste was 0.95% in relation to estimated delivered mass. In the waste prevention scenario the waste was reduced by 20% when the storage temperature was reduced from 4°C to 2°C.

Even when the waste reduction was only 20% of the wasted beef, the prevention scenario reduced the carbon footprint from the food waste more than any other waste management scenario (Figure 19). The second best alternative was anaerobic digestion, which reduced the carbon footprint by 0.7 kg CO_2e/kg food waste. This is much lower than the prevention scenario, which reduced the carbon footprint by 4.2 kg CO_2e/kg food waste. In the prevention scenario, 80% of the food waste was composted (in line with the donation scenario in Paper V) but if this waste were instead sent for anaerobic digestion, the benefit of the prevention measure would increase to a reduction of 4.8 kg CO_2e/kg food waste.

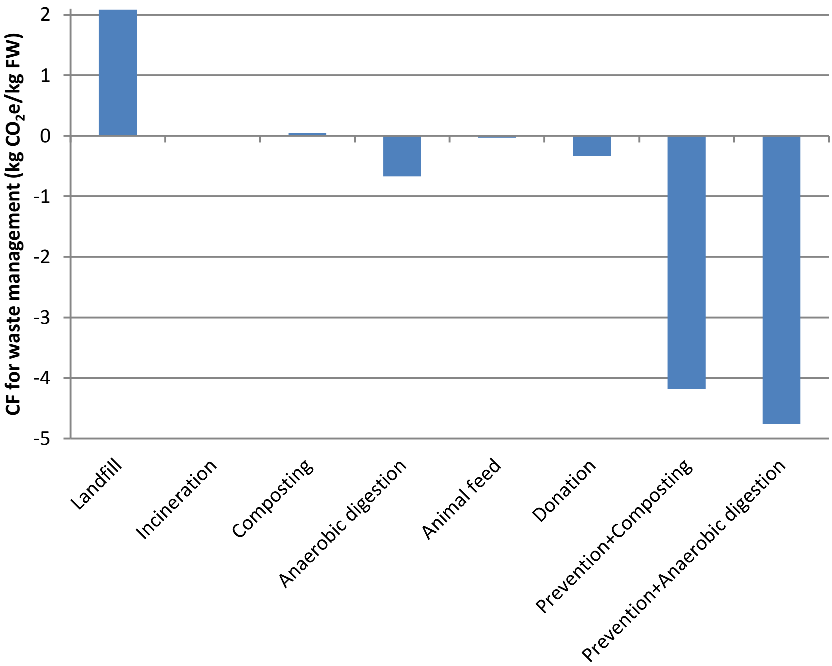

Figure 19. Comparison of different ways to manage all wasted beef in the supermarkets using a combination of scenarios in Paper IV and Paper V and the effects on carbon footprint (CF). In the prevention scenarios, 20% of the waste was prevented and 80% was managed by composting or by anaerobic digestion.

6 Discussion

Since only a small part of this thesis focused on causes of food waste, this discussion chapter focuses on quantities and measures in separate sections, while causes are included in both these sections.

6.1 Quantities of food waste

From the data presented in this thesis, it is clear that the waste composition is dominated by fruit and vegetables. This is well in line with other studies (*e.g.* Buzby & Hyman, 2012; Beretta *et al.*, 2013; Lebersorger & Schneider, 2014), although their dominance would probably have been reduced if bread had been included in the study (Scherhaufer & Schneider, 2011; Lebersorger & Schneider, 2014; Stensgård & Hanssen, 2014). Other studies do not include the pre-store waste that dominated the fruit and vegetable waste in the present case, but since the sum of pre-store and in-store waste from the stores investigated (4.7%) corresponded almost exactly to the most frequent waste level in Lebersorger & Schneider (2014), it is likely that the waste was at a normal level and that recorded cost was just booked differently than in supermarkets in other studies.

Even if the waste was on a similar level as other studies, there was considerable variation in the material. First, there was large natural variation within the stores over time and between articles. Data can also be presented using different units or relative numbers, which increases the number of possible perspectives although it does not actually increase variation.

6.1.1 Use of different units for quantification

Choice of analytical method had an effect on the results presented in this thesis. For example, all results presented in terms of mass resulted in bulky products with a high water content, *e.g.* fruit, vegetables and dairy products, having a large influence on the results. When the results were presented using the monetary value of the waste, more expensive products, *e.g.* herbs such as basil, gained importance at the expense of *e.g.* potatoes. Use of carbon footprint shifted the focus relatively more to meat and cheese products rather than fruit and vegetables and dairy. The weakness of using units of mass in this kind of study is that the products with a large environmental impact can be associated with low mass, which can be interpreted as meaning that they are not important (Strid, 2012). For this reason, the monetary value corresponds better to environmental impact than units of mass and would therefore work better as an indicator of environmental hotspots then analysing units of mass. The strength of using mass values is good transparency, since the unit is well-defined and does not change along the food supply chain, except during processing. Both monetary values and values describing the environmental impact need detailed definitions and have a tendency to differ over time and along the value chain, even without processes that change the properties of foodstuffs. For example, the value of products increases not only when they are processed, but also when they change owners, are transported or are kept in a cold storage.

Using a unit of mass makes the results comparable with those of other studies. However, it is not only the units that make comparisons complicated. Results based on monetary values are often compared with the value of sold products, since this is the basis of income in a company and the figure against which all costs must be compared. When percentage waste is as low as it was in this study, this causes no significant problems, since percentage waste of 1.00% calculated with Equation 1 corresponds to a value of 1.01% if the waste is compared with the sold value instead. The choice of comparison is more influential for products with higher values of percentage waste. Some of the exotic fruits described in Paper I, with waste of above 50%, would have values of over 100% if the waste were related to sold quantity instead of delivered quantity.

6.1.2 Data quality and selection of study objects

The six supermarkets used in this work were selected by the parent company, which introduces a possible bias, even though the company claimed that they represented the average. It is unlikely that the company selected stores with high percentage waste, since high levels of waste tend to be something shameful and might repel customers if the information became publicly available. Therefore the supermarkets studied can be expected to represent an average Willy:s store or have lower percentage waste than the average Willy:s store. The selected stores were also found to be larger than average in terms of turnover of fruit and vegetables (Paper I), which further increases the potential for them to waste less than average (Hanssen & Schakenda, 2011). However, even if the representativity cannot be proven, all supermarkets within the company are based on a detailed concept (Willy:s, 2010), making large variations between individual supermarkets unlikely. The level of waste in the six supermarkets investigated is therefore unlikely to differ greatly from the average supermarket within the Willy:s chain.

Material flow analysis performed in Eriksson (2012) showed that the unrecorded waste category and missing quantities differed in size between departments. These two categories are a good indicator of the quality of recorded data. If large quantities are lost without any reasonable explanation, a likely cause is that the recording of waste does not function well and items are discarded without recording. From the analysis, it is clear that data based on EAN code scanning are more accurate than data based on estimated weights. Therefore the results for cheese, dairy, deli and meat can be considered more accurate than those for FFV. This is true even though efforts were made to quantify unrecorded in-store waste of FFV by physical measurements.

6.1.1 Uncertainties in carbon footprint of food

The carbon footprint of the wasted food products in Paper III was mainly calculated based on the existing literature on LCA studies. Although the LCA methodology is ISO-standardised, the choice of some aspects, such as the exact system boundary, functional unit, allocation method or use of emission factors, is slightly open. Therefore, the results for the same product can vary and in general the results of different studies are not directly comparable. Moreover, for agricultural products the chosen production system and the production country is crucial. In this thesis work, most effort was put into getting the necessary background information and evaluating the carbon footprint that was most representative for the wasted products. However, in some cases rather broad assumptions had to be made.

The carbon footprint of the different deli products was calculated based on assumptions on meat content and energy requirements. Although information about the total meat content of the products was generally available, mostly no information about the exact content of meat type was given. Since most products contain beef and pork to some extent and the carbon footprint of beef is almost five times larger than that of pork, this could have a significant impact on the results. Moreover, the meat content of individual products can vary, for example between different brands. The meat content was generalised for different product categories and it was considered that the deviations were balanced on average. It was assumed that the non-meat content does not have any impact on the overall result, since other ingredients are usually products with a much lower carbon footprint than meat, for example water or potato starch, and the relative impact is low.

Estimating the carbon footprint of processed dairy products is difficult, since milk intake and other activities and the associated emissions can be allocated to different products. For example, butter fat can be seen as a byproduct from cheese production (Cederberg *et al*., 2009). Here, the wastage carbon footprint of most dairy products, including milk and other fresh dairy products, butter, butter blends and cheese, was calculated based on results from a study by Flysjö (2012). In that study, total emissions associated with dairy production of a large dairy company were allocated in a top-down approach to the different products and milk intake was calculated for the different products based on the weighted value of fat and protein. Only a limited number of other studies on processed products was available. Processed foods like cheese spreads and different deli products need to be analysed in more detail to establish more accurate carbon footprint values. When analysing meat products, development of a method to estimate the impact of different meat cuts and byproducts such as offal should be considered.

LCA studies on the production of fruit and vegetables often address only one or a few production sites, so the results are specific for the particular system. Since produce is often imported into Sweden from many other countries, the wastage carbon footprint was calculated based on the share of the product from its different countries of origin. Therefore, the focus was on finding LCA studies on the countries' typical production systems, which was not always possible. To give a picture of variations in a product's carbon footprint, tomatoes are used below as an example, since they have a high waste carbon footprint and therefore a dominant position in the waste carbon footprint of the whole fruit and vegetables department.

Tomatoes sold in the six supermarkets investigated mainly originated from the Netherlands and Spain. It can be assumed that most tomatoes are grown in greenhouses and for the carbon footprint it is crucial if these greenhouses are heated and, if so, how this heat are produced. For example, tomatoes grown in a heated greenhouse in Sweden have an estimated CF of 2.7 (Biel *et al*., 2006) or even 3.7 kg CO_2e/kg (González *et al*., 2011), while according to Davis *et al*. (2011) the average CF is 0.66 CO_2e/kg due to increasing use of biofuel in greenhouse heating. Reported values for Dutch production are between 0.78-2 kg CO_2e/kg (Antón *et al*., 2010) and 2.9 kg CO_2e/kg (Biel *et al*., 2006). In Papers III and IV, the value of 2 kg CO_2e/kg estimated by Antón *et al*. (2010) was chosen for Dutch tomatoes, since it considered the use of a combined heat and power plant, which is common in Dutch greenhouses. For Spanish production, the values range from 0.05 kg CO_2e/kg for production in the open field (Muñoz *et al.*, 2007) to 2.64 kg CO_2e/kg for baby plum tomatoes in heated greenhouses (William *et al.*, 2008). In Paper III, it was assumed that all Spanish tomatoes were grown in an unheated greenhouse tunnel. No distinction was made between different tomato varieties, even though William *et al.* (2008) showed that for example vine tomatoes are associated with higher emissions due to lower yields.

The analyses for other fruit and vegetable products were based on less complicated assumptions than were made for tomatoes, but due to lack of literature those for many products had to be based on LCA results for similar products or similar production systems. These assumptions potentially create large uncertainties, but when addressing a large variety of products produced in a variety of conditions, it is not possible to address each one of them in detail, which makes rough assumptions necessary.

Overall, the results have to be viewed with caution. LCA studies always include uncertainties (*e.g.* Röös, 2013), and for some products broad assumptions had to be made. Nevertheless, the results can be considered to give a good picture of the potential climate impact of food waste in the supermarkets studied and to reveal the differences between different product groups.

6.1.2 Issues regarding data quality for fruit and vegetables

The largest recorded mass flow of waste came from the fresh fruit and vegetable department, which could be a target for waste reduction measures just for this reason. In Paper I rejection was identified as the main cause of this large mass flow of waste, but since Paper I only covered data from 2010, it is clear that the additional results presented in this thesis make the result difficult to interpret. The first problem that must be addressed with rejections is their root cause. In theory, substandard quality should be the only reason for rejection (apart from the obvious reason that the food is missing on delivery and the store therefore refuses to pay for undelivered goods). However, Eriksson (2012) and Eriksson & Strid (2013) found that rejections can also be a consequence of efficient waste reduction. The example they use to illustrate this is that when a store decreases in-store waste of bananas, pre-store waste of bananas increases. If the shift were balanced so the total amount of wasted bananas remained the same, this would just be a matter of accounting, but Eriksson (2012) showed that the total banana waste increased, since the pre-store waste increased more than the in-store waste decreased. One explanation for this could be that supermarket staff put less effort into orders when the cost (to the individual supermarket) of wasting products decreases. However, one example cannot fully prove that this is not due to coincidence, and the result should be interpreted with caution.

Eriksson & Strid (2013) discuss the rejection problem in the context of waste reduction measures and suggest a limit on rejections as a way to reduce waste, which of course would be impossible if the products were truly unsellable. It can therefore be assumed that supermarkets use the system in a way that increase profits, but also increases wasted mass as a consequence. Tapper *et al*. (2013) describe this behaviour as opportunistic and argue that rejections are not at all due to opportunistic individuals, but to inexperienced staff and misunderstandings regarding quality requirements. Whether staff are driven by an opportunistic desire for easy profits or whether they are the victims of a system rewarding them for making decisions that lead to increased waste is a rather philosophical question that is not answered here. However, regardless of the reasons, product rejection is a problematic area and a hotspot for reduction measures.

In this context it is positive to see that the initial increasing trend in rejections of fruit and vegetables during 2011 peaked in 2012 and declined in 2013, to reach the lowest level in 2014, since total waste seemed to reflect pre-store waste (Table 4). The in-store waste showed the opposite trend, with low levels when the pre-store waste was high and higher levels when the pre-store waste was lower. However, since pre-store waste was much more dominant, the total effect was marginally influenced by the in-store waste.

There is also a problematic dimension of interpreting the results for the fruit and vegetable department due to the findings in Figure 6, where the missing quantities fraction was negative in four of the 30 yearly mass balances. From an environmental perspective it is of course positive that food does not get wasted, but from a scientific perspective it creates problems since it is difficult to explain and reveals a potentially large quality issue in the data set.

The reason for the negative missing quantities cannot be fully clarified and the only way to approach this problem is to discuss a broader range of possible explanations, including why some explanations are less likely than others. The missing quantities can of course have natural causes, like corrupt data, but since great resources are put into data recording, great uncertainties seem unlikely. The discrepancy could be due to deliveries that are heavier than declared, *e*.g. the supplier expects a weight loss due to evaporation and therefore loads a box with 5.5 kg tomatoes with declared weight of 5 kg. If the evaporation is less than the expected 10%, the supermarket can actually sell more tomatoes than it bought according to the records. This probably occurs, but it is an unlikely explanation since the evaporation should be similar for all stores, and if the storage conditions are not changed drastically the evaporation would be expected to be the same every year.

An outflow that is larger than the inflow is not a possible explanation, but this would be possible if data were corrupt in a way whereby the supermarket could not only reclaim the money for some goods, but also sell them. This would appear to be highly immoral and opportunistic, but could also have less opportunistic reasons, such as bad routines that make overestimation of rejections possible. One supermarket had a routine of always rejecting two boxes of peppers for every pallet of peppers delivered. This was not because they wanted to ‘steal’ the peppers, but because they did not want to waste time going through all the boxes and sorting out the bad ones. Just by making an innocent and reasonable assumption like this, it would be possible to receive a shipment of food, reject two boxes and then sell the whole shipment, creating an outflow that is 10 kg larger than the inflow. Whether this is immoral or not is for others to debate, but if this is a true explanation it reduced the actual waste of fruit and vegetables, even though the records indicated differently. It also indicated that if waste records within fruit and vegetable departments cannot be trusted, a better way to investigate this waste should be devised, *e.g.* by comparing delivered with sold mass rather than the waste records.

6.1.3 Comparison of indicator values of waste generation

When only using the quantification data for calculating the relative waste, the choice of method for calculating the waste appeared to be of less importance, since Table 2 shows a large variation in methods used, but not large differences in results. However, this can be due to the fact that most studies are based on aggregated data, which compensate for the variations in different articles or stores. When quantitative data from limited case studies are used for estimating national levels of national food waste, it is clear that variations can strongly influence the results. For example, Figure 20 compares a key figure, waste per full time employee, for the supermarkets studied in this thesis and other Scandinavian studies that have used this key figure to estimate the national waste. It is clear that the mean value used varies between the studies and for example that the waste in Denmark (Miljøstyrelsen, 2014; Landbrug & Fødevarer, 2015) is much higher than in Sweden (Stare *et al.*, 2013; SEPA, 2013). Why Danish supermarket waste (153 000 tons/year or 27 kg/capita) is more than double that in Sweden (70 000 tons/year or 7 kg/capita) is not easy to explain, since the countries could be expected to be fairly comparable. However, since the values on which both studies base their estimates vary widely between minimum and maximum and overlap each other, it is possible that a different selection of supermarkets would give a very different result. In

Figure 20, it is clear that at least the six Swedish stores investigated in this thesis have a waste level more similar to the Danish estimate (Miljøstyrelsen, 2014) when including pre-store waste. They also showed smaller variation than the other studies, but the variation was still large considering that these six stores are likely to be very similar in comparison with the variety of stores used in the other studies.

One possible explanation for the great difference between results in Stare *et al*. (2013) and the present thesis, beside the selection of stores, is the discount profile of the stores concerned. Since labour costs are fairly high in Sweden, it is possible that the supermarkets investigated here have been able to cut costs more on staff than on food waste, giving a waste per employee figure that is higher than in other stores that are more heavily staffed. This agrees with the results from Miljøstyrelsen (2014), where discount stores had the highest level of waste per employee of all types of store investigated.

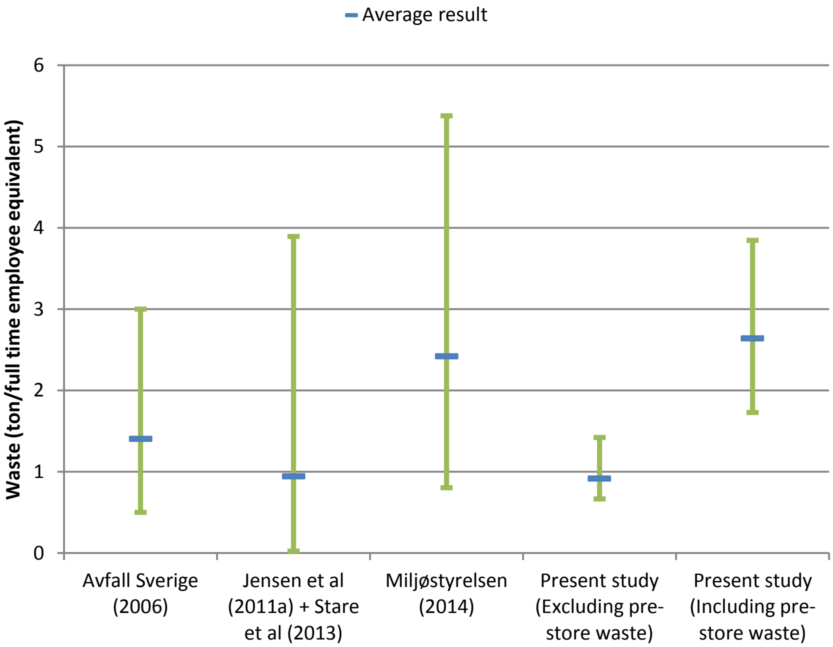

Figure 20. Comparison of three studies reporting values for waste per employee in supermarkets. The mean, max and min values are presented, together with values from this thesis both including and excluding pre-store waste based on five-yearly values for the six supermarkets studied. Mean values are taken from Stare *et al*. (2013), but min and max values are taken from Jensen et al. (2011a).

6.2 Waste reduction measures

6.2.1 Perspectives on waste prevention and valorisation

The food waste management framework presented in Figure 7 can be used to better understand the conceptual differences of waste reduction measures. It also gives a brief overview of how all of these measures can be evaluated with a similar methodology in order to make the results comparable, even though waste prevention and waste management are often regarded as completely different processes (van Ewijk & Stegemann, 2015). The key to evaluating prevention measures as if they were waste management options is to focus on the substituted products in a system expansion. In the present case, the prevented food waste replaced another identical product that was never produced, distinguishing source reduction measures from valorisation measures that use the food waste to substitute for products or services that are likely to not be identical to the original product, even though they could replace an identical product in the best case.

The environmental impact of` all waste management options, both prevention and valorisation, depend heavily on the substituted product and the cost of making the substitution possible. Since the original product is often the most resource-dependent product that can be substituted, source reduction is normally the most favourable way to manage waste. However, if the cost of prevention is higher than that of the substituted system, the net effect will be negative, meaning that introduction of the measure will result in a net cost. To make this even more complicated, both the substituted system and the cost of waste management can be measured in different values, such as money or climate impact, since some measures can be beneficial from an environmental perspective, but too expensive to be economically favourable (Paper IV).

The complication of valuing waste in different units is clear from the measures of economic valorisation included in the framework in Figure 7. To put it simply, these measures aim to recover at least some of the economic value invested in the products instead of just throwing them away. The most obvious example of such a measure is price reduction, where the whole product is sold (and hopefully consumed). This means that waste is prevented, but in comparison with selling the product at full price it represents a loss of some, but not all, money. These measures are still considered prevention, since the food is sold instead of being wasted, but they are fundamentally different to other prevention measures that lead to source reduction. In order to put this into the suggested food waste management framework (Figure 7), the economic valorisation measures were assumed to replace food products that are similar, but not necessarily identical, to the original product. An example of this could be a customer looking for a piece of meat in a certain price range and buying a piece of expensive meat with a price reduction instead of a planned product. In this example, the customer would not have bought an expensive product if the price had not been reduced, but a similar product with a lower price. The measure therefore substituted for production of similar (and probably cheaper) but not identical production. Another example of this is presented in Strid & Eriksson (2013), where meat cuts were sold to a catering company. There all meat cuts were assumed to replace a cheaper alternative, but since all meat cuts from the same animal were associated with the same CF per unit mass, the loss of carbon footprint was small due to this downcycling.

The other measures in Figure 7 that provide less favourable waste management options than prevention can all be viewed as traditional waste management methods. Most of the waste management scenarios use the food waste to produce some kind of product that replaces another production system with decreased value following the hierarchy down to the landfill scenario. In that final scenario, no substitution is achieved and instead methane is produced, which gives a higher carbon footprint than if the food had been left to degrade in the air and just produce carbon dioxide (Paper V).

Another perspective on waste reduction measures is whether they are specific or general, *i.e.* whether they can handle all kinds of food or just a specific quality and/or specific products. The general measures are all waste management options rather than waste prevention measures. Examples of such general measures are incineration and composting, since all food products can be used and transportation and management can therefore be handled at a low cost. Examples of specific measures are donation, where only a safe quality of the food can be given away and which requires more expensive logistics with more frequent collections and chilled transport in order to keep the food safe until consumption. Since the specificity of measures increases with increased priority in the waste hierarchy, the top alternatives often require more sorting or logistics, which makes them more expensive. On the other hand, they also produce more valuable products, which can lead to a net benefit for the supermarkets (Eriksson & Strid, 2013) or for society. Since the measures have different benefits and costs, a combination of several measures can be seen as the optimal solution, where some of the waste is reduced at source with prolonged shelf-life (Paper IV), some is sold at a price reduction (Eriksson & Strid, 2013), the surplus food that meets quality requirements is given to charity (Paper V) and the rest is treated with the best available general waste management option, such as anaerobic digestion (Paper V).

All waste reduction measures have different characteristics and some important features, such as cost and potential savings, are often the main focus.

For example, reduced storage temperature for dairy products (Paper VI) has a high waste reduction potential since it reduces the wasted mass, but the net savings of reduced carbon footprint of the waste reduction are not enough to cover the high cost of reduced storage temperature, which makes this an inefficient measure, but still with the ability to reduce food waste. For meat products, the savings from reducing storage temperature exceed the costs, which gives a net saving, but the ability to reduce the wasted mass is lower than for dairy products. This shows that waste reduction potential is important, but since the actual goal of reducing food waste is to reduce the consequences of the waste, the net benefit in terms of money or emissions must be considered.

Even though reduced storage temperature does not have a reducing effect on carbon footprint in all supermarket departments (Paper IV), a comparison of beef products (Figure 19) clearly shows the potential of source reduction in comparison with other waste management options from Paper V. Beef is the most extreme example due to the large carbon footprint per unit mass (Paper III), but it is clear that even a 20% reduction by far exceeds the outcome of the best general waste management scenario, which in this case was anaerobic digestion. The large difference in outcome from source reduction compared with waste management was also observed by Bernstad Saraiva Schott & Andersson (2014). This confirms that the exact order of priority of waste management options might not fully agree with the EU waste hierarchy (Paper V), but placing prevention in the most favourable position seems to be correct. Efforts should therefore focus on source reduction whenever possible, even if the waste reduction potential is small. In most cases even a small reduction will reduce the carbon footprint from the wasted food much more than any waste management option, and the most favourable waste management option should therefore only be applied to waste that cannot be prevented.

6.2.2 Factors influencing the evaluation of waste reduction measures

There are several limitations with the theoretical evaluations of waste prevention and valorisation options used in this thesis. They simplify complex systems and use assumptions that do not necessarily represent reality, and therefore the results should be interpreted with caution and other analyses should be performed to either support or disprove the results. However, since the field had not been investigated previously, this early study should be seen as a starting point for a process of increased knowledge, rather than the end point.

In Paper IV, many assumptions had to be made in order to link the processes of reduced waste, increased shelf-life and increased electricity use.

This created many possibilities for small divergences from reality, which can eventually add up to a large divergence. However, one assumption that had a strong influence on the results was the carbon footprint associated with electricity production. Depending on the electricity mix used, the results will vary widely, from negative to positive savings, according to the sensitivity analysis in Paper IV. Since there were also other ways to achieve the temperature reduction, such as installing cabinet doors, there is great potential to come up with a solution that includes significantly larger savings than presented in Paper IV. It could therefore be questioned whether a temperature reduction only gives net savings for fresh meat products, as concluded in Paper IV.

Paper V also included assumptions that could be varied, thereby creating variation in the results. The difference from Paper IV is that Paper V investigated a series of parallel scenarios that only influenced each other to a very small extent, while Paper IV examined a longer chain of processes where small errors had a higher risk of adding up to large errors.

One assumption with potential influence on the results in Paper V is that the composting scenario did not replace any product or service in the system expansion. This assumption was made with the limitation that it should describe the current situation. However, if the compost were to replace *e.g.* peat for soil improvement, larger savings could be achieved in this scenario, although this would require the full potential of the compost to be used to replace peat and not just added to the soil as described in Andersen *et al.* (2010). Moreover, even if the full potential of the compost is utilised, it is still unlikely that it will be enough to drastically change the order of priority of the scenarios.

6.3 Potential to increase sustainability by reducing food waste

The potential to reduce food waste should not only be related to the cost of reducing waste, but also to other possible measures that lead to increased sustainability. In order to put the problem of food waste into context, it can be compared with other sources of carbon footprint presented in the Axfood Sustainability Report (Axfood, 2014). Using the data in that report, the average carbon footprint on specific services during 2012-2014 was recalculated into a value of emissions per supermarket (of which six out of 246-259 are the stores investigated here). This value was set to 71 ton CO_2e/supermarket/year originating from electricity use in the supermarkets (excluding wholesale facilities), 3 ton CO_2e/supermarket/year from business flights and 39 ton CO_2e/supermarket/year from transport of goods in the 137 company-owned trucks. When these three sources of emissions were added together, they were still lower than the average carbon footprint associated with food waste, which was estimated to be 131 ton CO_2e/supermarket/year (Paper III and Appendix I). Since these are average values, they are likely to include some variation and therefore some stores can diverge from this pattern, but since the key figure for food waste is so much larger than the other key figures, reducing food waste should clearly play an important role in work towards sustainable development.

In the sustainability report of the parent company of the stores investigated (Axfood, 2014), food waste is mentioned several times, but there are no actual goals set for reducing this waste. This could be because the company does not want to declare exact amount for food waste, because it is difficult to measure in comparable units such as ton or ton CO_2e or simply because food waste gives rise to emissions long before they reach the stores and therefore is considered to be outside the sustainability work of the retailer. It could also be because the company does not see the same potential in reducing this problem as can be achieved with other problems. Just because a problem is large does not mean that there is a large savings potential in solving it. However, the results in Paper IV indicate that a waste reduction through a temperature reduction (from 4°C to 2°C) and increased shelf-life in the meat department could reduce the CF by 12 ton CO_2e/supermarket/year. This waste reduction could be related to the goals of reduced emissions from flights, energy use and transport by multiplying the average emissions by the goal set (as a percentage) to get the wanted reduction in absolute terms. However, this is a simplification, since all goals are set in relative terms, *e.g.* in relation to floor area or ton transported, so that company growth does not interfere with sustainability goals. The goals also have different base years, so relating the goal to an average emissions level must be considered a rough estimate, but still gives an indication of the relative magnitude of the potential. For the supermarket company in this thesis, a goal of 15% less emissions from business flights corresponded to a reduction of 0.4 ton CO_2e/supermarket/year, a 10% reduction in transport emissions corresponded to a saving of 4 ton CO_2e/supermarket/year and a 25% reduction in electricity[4] consumption correspond to savings of 18 ton CO_2e/supermarket/year. These goals can be related to the potential in shifting waste management method from composting to anaerobic digestion (assuming that all waste corresponds to bananas in the composting and anaerobic digestion scenarios in Paper V), which would potentially save 34 ton CO_2e/supermarket/year. It can also be related to the potential savings of 12 ton CO_2e/supermarket/year achievable by reducing

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[4] The goal in Axfood (20014) states energy consumption, but here it was assumed that this includes a 25% reduction in electricity-related emissions.

storage temperature in the meat department (Paper IV). A complicating factor is of course that the local infrastructure might not make it possible to shift waste management to anaerobic digestion. Another is that reducing waste through reduced storage temperature will consume more electricity, according to the assumptions used in Paper IV, and therefore conflict with the goal of reduced energy consumption. However, whether the temperature reduction is achieved through better cleaning routines for the chill cabinets, as suggested by Danielsson-Tham & Bood (2015), by using doors on vertical cabinets (Lindberg *et al.*, 2010) or by changing to an electricity mix with lower CF (Paper IV), the goals of reduced energy-related emissions and reduced food waste can both be achieved without conflict.

7 Conclusions

This thesis made a deeper investigation than most previous studies of food waste in supermarkets and it provides new information about quantities of wasted food, data quality issues, risk factors and potential net savings from different prevention and waste management options. From this information, it is clear that waste increases the carbon footprint of food and that waste reduction has the potential to reduce the carbon footprint from the food supply chain. Since there was found to be a lack of tools and definitions regarding supermarket food waste issues, new approaches and new combinations of methodologies were developed during the work in order to meet the objectives.

From the overall data presented, a few more general conclusions can be drawn than are presented in the individual papers. First, the fruit and vegetable department had the largest recorded wasted mass, with most of this recorded waste coming from rejections. However, when this waste was measured as the difference between delivered and sold products the figure is lower, which reduced the significance of this problem and also the potential to reduce waste by limiting rejections. While physical rejections may be less than supermarket financial records indicate, the largest share of wasted mass was still found in the fruit and vegetable department and was dominated by rejections on delivery to the supermarket.

When the carbon footprint, instead of mass, was used to evaluate the waste, the meat department increased in importance and the fruit and vegetables department lost some of its dominance. Other supermarket departments with mainly products of animal origin contributed a larger share of waste when the carbon footprint was considered rather than the mass of waste.

Reducing the storage temperature proved to have the potential to increase shelf-life which can lead to reduced waste. However, the way of achieving this temperature reduction was of great importance for achieving a net saving in terms of both carbon footprint and money. By using other alternatives than increased use of the average electricity mix, a net saving for products other than just meat would be possible. On comparing waste management options with prevention measures, source reduction of beef waste was found to decrease the carbon footprint much more than all valorisation measures investigated.

For food waste that cannot be prevented, valorisation options should be used to reduce the negative effects of food waste. This can be achieved mainly by replacing other products in a substituted system. Target products for efficient waste valorisation measures should therefore be foodstuffs that can be used to replace other products or services that are expensive, resource-demanding and/or have a high carbon footprint. When considering only carbon footprint, bread is a good example of a high priority target for waste valorisation due to its low water content, which allows it to carry much energy that can be used for various purposes.

Waste reduction measures specialised for a specific food product tend to be more environmental efficient than general waste management options, whereas the latter instead have the ability to handle more waste with less restrictions on quality. Since most food products have high water content, a mixed flow of supermarket food waste will be most efficiently managed by anaerobic digestion for production of biogas that can replace resource-demanding products or services. However, since supermarket food waste is by nature separated before it reaches the waste container, it has the potential to be used differently depending on the nature of the wasted products. Therefore a combination of prevention, economic valorisation, donation, conversion and recovery should be practised simultaneously in order to find efficient ways to reduce the carbon footprint of the food supply chain.

8 Future research

Food waste in supermarkets is a quite narrow research field, but expansion would be desirable due to the potential to reduce both cost and environmental impact. This thesis digs deeper than many other studies, but still just uncovers the tip of the iceberg. Therefore it is a continuing need to advance the knowledge frontiers. Some suggested fields that needs to be further investigated are:

- Risk factors need to quantified in terms of waste generation: Which risk factors are relevant for supermarkets? What quantities do they generate? and Under what circumstances?
- Measures aimed at reducing food waste must be further investigated. This includes more theoretical simulations to find promising waste interventions, but also practical tests where the measures are evaluated in real situations. Such theoretical and practical evaluations should include both the costs of performing the measure and the potential waste reduction, so a net result can be achieved.

Food waste research in supermarkets has come quite far in comparison with that by other actors in the food supply chain. Other actors therefore have the opportunity to learn from supermarkets in order to improve methodology, perhaps by simply replicating the work in this thesis but with the perspective shifted to food services, industry, household, and so on. Some suggestions are:

- Continuous quantification must be performed, since waste varies widely between different sectors, but also over time within the same sector. If only selected periods or waste fractions are quantified, they should at least be randomly selected so that it is not only the periods with the lowest levels of waste that are quantified.
- After establishing robust food waste quantification routines, systematic work to reduce food waste can start. If interventions are tested without

sufficient quantification, monitoring will be impossible and it will be unclear whether the measure reduces food waste at all.

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Appendix I. Store department level results.

This appendix contains three tables showing the sum of sold and wasted food in terms of mass, carbon footprint and money on supermarket department level. Waste includes recorded in-store waste and pre-store waste, and relative waste is calculated in relation to the sum of sold and waste (Equation 2).

Table AI.1. *Summarised values of mass of sold and wasted perishable food from different departments in all six supermarkets studied during five years 2010-2014.*

Department	Sold (ton)	Waste (ton)	Relative waste (%)
Cheese	5 000	28	0.55
Dairy	52 000	180	0.34
Deli	5 800	91	1.5
Fruit and vegetables	42 000	2 000	4.7
Meat	6 800	88	1.3
Total	110 000	2 400	2.1

Table AI.2. *Summarised values of CF associated with the sold and wasted perishable food from different departments in all six supermarkets studied during five years 2010-2014.*

Department	Sold (ton CO_2e)	Waste (ton CO_2e)	Relative waste (%)
Cheese	44 000	240	0.54
Dairy	75 000	250	0.33
Deli	34 000	530	1.5
Fruit and vegetables	35 000	1 700	4.7
Meat	110 000	1 200	1.1
Total	300 000	3 900	1.3

Table AI.3. *Summarised economic value of sold and wasted perishable food from different departments in all six stores studied during five years 2010-2014. The value given is the cost without value-added tax for the store to buy the food and pre-store waste is valued to this price.*

Department	Sold (MSEK)	Waste (MSEK)	Relative waste (%)
Cheese	319	1.6	0.50
Dairy	701	2.3	0.32
Deli	296	4.0	1.3
Fruit and vegetables	657	32	4.7
Meat	355	5.3	1.5
Total	2 330	45	1.9

Appendix II. Food category level results.

This appendix contains five tables, one for each department, showing the most dominant categories in terms of wasted mass. All values represent the sum for all six stores investigated during five years. The figures include results of sold mass; wasted mass both in-store and pre-store; the number of articles included in each category; average waste per article in each category; and wasted mass in relation the sum of wasted mass and sold mass (Equation 2).

Table AII.1. *All eleven categories studied, ranked in terms of recorded wasted mass, in the cheese department*

Category	Sold (ton)	In-store waste (ton)	Pre-store waste (ton)	Number of articles sold (n)	Waste per article (kg/art)	Relative waste (%)
Dessert cheese	360	5.0	0.22	204	26	1.5
Hard cheese mild/medium	1 200	4.7	0.45	117	44	0.42
Hard cheese mature	540	4.6	0.30	121	41	0.91
Hard cheese mild	970	4.0	0.46	74	60	0.46
Cheese in food	670	2.4	0.046	186	13	0.36
Sliced cheese	270	1.3	0.12	74	19	0.52
Hard cheese medium	310	1.1	0.12	57	21	0.39
Bagged cheese	220	1.2	0.021	84	14	0.53
Cheese spread	170	0.66	0.086	95	7.9	0.43
Grated cheese	230	0.65	0.008	41	16	0.28
Whey cheese	62	0.24	0.042	13	22	0.45

Table AII.2. *The top 14 categories (out of 22) in terms of recorded waste in the dairy department*

Category	Sold (ton)	In-store waste (ton)	Pre-store waste (ton)	Number of articles sold (n)	Waste per article (kg/art)	Relative waste (%)
Milk	20 000	48	0.44	85	570	0.24
Chilled juice	5 700	25	0.38	162	160	0.45
Flavoured yoghurt	4 400	18	0.24	280	66	0.42
Sour milk	3 500	17	0.29	97	180	0.50
Cream products	3 400	14	0.29	160	92	0.43
Eggs	3 200	10	1.1	46	240	0.35
Juice	1 700	6.4	0.16	79	83	0.38
Non-dairy alternative products	2 000	5.1	0.38	89	62	0.27
Food fat for spreading	1 800	4.7	0.048	62	76	0.26
Low calorie drinks	1 300	4.4	0.060	71	63	0.34
Cottage cheese	700	4.2	0.076	62	69	0.61
Yoghurt	1 700	3.2	0.13	23	150	0.20
Food fat for baking	1 500	3.2	0.043	36	89	0.22
Chilled desserts	370	2.4	0.086	67	37	0.68

Table AII.3. *The top 14 categories (out of 16) in terms of recorded waste in the deli department*

Category	Sold (ton)	In-store waste (ton)	Pre-store waste (ton)	Number of articles sold (n)	Waste per article (kg/art)	Relative waste (%)
Barbecue sausages	1 100	17	4.4	201	100	1.9
Cold cuts	980	14	4.7	506	37	1.9
Wiener sausages	470	10	1.9	78	150	2.5
Salted or smoked deli	200	6.3	3.4	59	170	4.6
Thick sausages	960	4.2	1.4	61	91	0.6
Meatballs	610	4.6	0.46	28	180	0.8
Pâtés	290	3.6	1.1	79	61	1.6
Smoked pork loin	270	2.9	0.43	15	220	1.2
Luncheon meat	110	2.3	0.54	64	44	2.5
Blood pudding	250	1.5	1.3	18	160	1.1
Bacon	460	2.2	0.33	47	54	0.5
Head-cheese	30	1.0	0.24	22	58	4.0
Deli – no cold storage	40	0.32	0.15	49	10	1.1
Pickled food	5.8	0.38	0.34	28	15	6.7

Table AII.4. *All nine categories studied, ranked in terms of recorded wasted mass, in the fresh fruit and vegetables department*

Category	Sold (ton)	In-store waste (ton)	Pre-store waste (ton)	Number of articles sold (n)	Waste per article (kg/art)	Relative waste (%)
Everyday vegetables	13 000	150	550	228	3.1	5.2
Everyday fruits	11 000	71	500	111	5.2	4.8
Luxury fruits	4 100	60	230	98	2.9	6.6
Luxury vegetables	1 500	34	90	91	1.3	7.4
Herbs	4 000	42	73	137	0.8	2.8
Potatoes	7 300	57	53	33	3.3	1.5
Exotic fruits	680	24	15	46	0.86	5.5
Berries	190	7.7	18	21	1.2	12
Pre-cut lettuce	4.8	0.07	0	29	0.0023	1.4

Table AII.5. *The top 14 categories (out of 30) in terms of recorded waste in the meat department*

Category	Sold (ton)	In-store waste (ton)	Pre-store waste (ton)	Number of articles sold (n)	Waste per article (kg/art)	Relative waste (%)
Swedish pork	804	20	0.69	177	120	2.5
Swedish poultry	1 200	17	0.18	133	130	1.4
Swedish beef	390	12	0.057	113	110	3.0
Swedish minced meat	1 800	8.6	0.051	62	140	0.47
European beef	310	5.1	0.040	32	160	1.6
Imported pork (case ready packed)	220	4.4	0.088	24	190	2.0
Imported pork	600	3.6	0.018	29	130	0.60
Imported minced meat	650	2.7	0.002	10	260	0.42
Raw sausages	11	1.9	0.004	11	170	15
Imported lamb	87	1.2	0.16	62	22	1.6
South American beef	89	1.2	0.011	36	34	1.4
Swedish veal	14	1.2	0.012	21	56	7.7
Chitterlings	7.5	1.0	0.003	7.0	140	12
Christmas ham	240	0.77	0.18	38	25	0.40

Appendix III. Food product level results

This appendix contains five tables, one for each department, showing the most dominant products in terms of wasted mass. The product level is a created level of aggregation that in some cases can equal a single article and sometimes a whole food category. The level is created to display results of products such as bananas, apples and meatballs, in order to make the results comparable with those in other studies of supermarkets with other articles and food categories.

The figures include results on the number of articles included in each product; the wasted mass and the carbon footprint of this waste for all six stores during five years; the share of waste (in terms of mass and CF respectively) in each department; and the wasted mass in relation the sum of wasted mass and sold mass (Equation 2).

Table AIII.1. *The top 20 products in terms of wasted mass in the cheese department*

Product	Number of articles (n)	Wasted mass (ton)	Waste CF (ton CO_2)	Share of department wasted mass (%)	Share of department wasted CF (%)	Relative wasted mass (%)
Gouda	46	2.5	24	9.0	10	0.30
Herrgård cheese	32	2.3	22	8.3	9.2	0.77
Hushålls cheese	53	2.3	21	8.1	8.8	0.32
Präst cheese	44	2.0	19	7.3	8.1	0.45
Brie	32	1.9	16	6.9	6.6	1.0
Soft cream cheese	83	1.2	6.6	4.3	2.8	0.52
Mozzarella	28	1.1	7.9	4.1	3.3	0.75
Cheddar	33	1.1	10	3.9	4.3	0.94
Edam cheese	40	1.0	9.1	3.6	3.8	0.50
Grevé cheese	24	1.0	9.4	3.6	4.0	0.40
Salad cheese/Feta	77	0.86	6.1	3.1	2.6	0.28
Cheese spread	94	0.74	2.9	2.7	1.2	0.44
Gorgonzola	12	0.47	3.8	1.7	1.6	2.0
Blue cheese	24	0.40	3.3	1.4	1.4	0.80
Billinge cheese	8.0	0.35	3.4	1.3	1.4	1.0
Jarlsberg cheese	10	0.34	3.3	1.2	1.4	1.1
Svecia cheese	7.0	0.32	3.1	1.1	1.3	2.3
Whey cheese	13	0.28	0.45	1.0	0.19	0.45
Port Salut cheese	10	0.27	2.5	1.0	1.1	0.40
Emmental	9.0	0.15	1.4	0.53	0.60	0.61

Table AIII.2. *The top 20 products in terms of wasted mass in the dairy department*

Product	Number of articles (n)	Wasted mass (ton)	Waste CF (ton CO_2)	Share of department wasted mass (%)	Share of department wasted CF (%)	Relative wasted mass (%)
Semi-skimmed milk	37	23	22	13	9.0	0.18
Flavoured yoghurt	309	20	24	11	10	0.42
Skimmed milk	20	15	14	8.7	5.8	0.47
Orange juice	84	13	8.0	7.3	3.3	0.33
Whole milk	26	12	13	6.6	5.3	0.21
Sour milk	60	11	12	6.4	4.8	0.37
Eggs	44	11	16	6.3	6.6	0.35
Apple juice	55	9.3	5.7	5.3	2.3	0.59
Cream	79	8.2	36	4.6	15	0.45
Butter blends	109	8.1	32	4.6	13	0.24
Flavoured sour milk	43	7.5	7.9	4.2	3.2	1.2
Cottage cheese	73	4.5	14	2.3	5.6	0.62
Plain yoghurt	24	3.7	4.5	2.1	1.9	0.21
Crème fraiche	69	3.2	11	1.8	4.6	0.44
Tropical juice	18	2.4	1.5	1.3	0.60	0.38
Strained yoghurt	22	2.2	5.5	1.3	2.3	0.31
Sour cream	15	2.1	5.8	1.2	2.4	0.50
Cranberry juice	8	1.1	0.37	0.63	0.15	0.78
Smoothies	42	1.0	0.68	0.58	0.28	1.8
Rice milk	21	0.90	1.1	0.51	0.45	0.43

Table AIII.3. *The top 20 products in terms of wasted mass in the deli department*

Product	Number of articles (n)	Wasted mass (ton)	Waste CF (ton CO_2)	Share of department wasted mass (%)	Share of department wasted CF (%)	Relative wasted mass (%)
Barbecue sausage	67	13	59	14	11	1.8
Wiener sausage	52	8.8	46	10	8.7	2.7
Smoked ham	90	5.0	28	5.5	5.3	1.3
Meatballs	19	4.5	46	4.9	8.8	0.75
Salted pork	20	4.2	24	4.7	4.6	4.0
Liver pâté	63	4.0	3.8	4.5	0.72	1.4
Cooked ham	40	4.0	22	4.4	4.3	3.6
Falun sausage	22	3.7	19	4.1	3.7	0.50
Smoked pork loin	15	3.3	18	3.7	3.5	1.2
Blood pudding	18	2.8	1.0	3.1	0.19	1.1
Chorizo	45	2.7	18	3.0	3.4	1.1
Prins sausage	22	2.6	13	2.9	2.5	2.0
Bacon	49	2.5	14	2.8	2.8	0.54
Smoked pork shoulder	10	2.3	13	2.5	2.4	8.0
Salami	121	2.2	24	2.5	4.5	1.4
Medwurst	37	1.5	7.9	1.7	1.5	2.1
Head cheese	22	1.3	7.7	1.4	1.5	4.0
Cured ham	54	1.1	8.4	1.3	1.6	1.8
Bratwurst	14	1.0	8.8	1.1	1.7	2.6
Mortadella	20	0.69	4.2	0.76	0.80	1.1

Table AIII.4. *The top 20 products in terms of wasted mass in the fresh fruit and vegetables department*

Product	Number of articles (n)	Wasted mass (ton)	Waste CF (ton CO_2)	Share of department wasted mass (%)	Share of department wasted CF (%)	Relative wasted mass (%)
Tomatoes	33	215	330	10	18	6.8
Bananas	9	210	231	9.8	13	5.7
Lettuce	57	183	99	8.5	5.4	9.7
Oranges	6	137	85	6.3	4.6	5.6
Peppers	19	134	310	6.2	17	9.4
Apples	59	120	47	5.6	2.5	3.6
Clementines	5	117	78	5.4	4.3	7.3
Potatoes	33	115	14	5.4	0.75	1.6
Melons	34	97	90	4.5	4.9	5.7
Cucumbers	15	69	65	3.2	3.6	3.9
Grapes	14	66	38	3.1	2.1	9.2
Nectarines	5	63	37	2.9	2.0	8.8
Pears	31	57	23	2.7	1.3	5.4
Mushrooms	17	55	22	2.5	1.2	12
Onions	33	48	14	2.2	0.78	1.8
Avocadoes	5	43	24	2.0	1.3	5.7
Carrots	14	42	5.5	2.0	0.30	2.1
Herbs in pots	39	36	36	1.7	2.0	12
Lemons	4	31	21	1.4	1.1	3.3

Table AIII.5. *The top 20 products in terms of wasted mass in the meat department*

Product	Number of articles (n)	Wasted mass (ton)	Waste CF (ton CO_2)	Share of department wasted mass (%)	Share of department wasted CF (%)	Relative wasted mass (%)
Pork chops	57	7.8	47	8.9	4.0	1.3
Minced beef	32	7.1	200	8.1	17	0.33
Pork leg	42	5.8	33	6.6	2.8	1.7
Spareribs	41	4.7	17	5.4	1.5	3.5
Grilled chicken	12	4.3	9.5	4.9	0.81	6.0
Chuck steak	19	4.3	120	4.9	10	2.3
Chicken leg	43	4.2	9.8	4.7	0.83	1.8
Beef steak	48	4.1	130	4.7	11	3.9
Ham	26	4.1	25	4.7	2.1	3.5
Chicken breast	42	4.1	11	4.6	0.97	1.4
Minute beef	13	3.0	88	3.5	7.5	1.7
Roast beef	29	2.9	86	3.3	7.3	2.3
Chicken whole	13	2.9	6.2	3.3	0.53	0.53
Mixed minced meat	25	2.7	46	3.0	4.0	0.81
Entrecôte	37	2.2	67	2.5	5.7	2.1
Pork shoulder	14	2.0	13	2.3	1.1	6.2
Raw pork sausage	4	1.6	13	1.8	1.1	16
Pork tenderloin	33	1.5	9.3	1.7	0.80	0.35
Minced pork	15	1.0	5.9	1.1	0.50	2.4
Lamb steak	22	0.90	17	1.0	1.4	1.0

Appendix IV. Article level results

This appendix contains eight tables, two for each department except FFV, displaying the most dominant products in terms of wasted mass and relative waste, respectively. All values represent the average waste per year and store and include both recorded in-store waste and pre-store waste. Relative waste is calculated using wasted mass in relation the sum of wasted mass and sold mass (Equation 2).

Fresh fruit and vegetables are excluded from this appendix, since data on pre-store waste were not available on article level. This is due to the separate article number systems used by the stores and the supplier.

The first four tables show results for wasted mass and wasted carbon footprint per store and year, relative wasted mass and the aggregated share of the departments wasted CF. The latter four tables show the sum for all six supermarkets during five years of wasted mass, sold mass and relative wasted mass.

Table AIV.1. *The 10 articles making the highest contribution to the CF associated with waste in the cheese department*

Article (% fat content)	Wasted mass (kg/store/yr)	Relative wasted mass (%)	Wasted CF (kg CO_2e/store/yr)	Aggregated share of department wasted CF (%)
Präst 35%	18	0.6	170	2.1
Brie 32%	20	1.5	160	4.2
Herrgård 28% Mild	14	1.1	130	5.9
Gouda 28%	12	0.3	120	7.3
Herrgård 28%	11	2.8	110	8.7
Gouda slices 27%	10	0.5	95	9.9
Cheddar whiskey 32%	10	5.7	94	11.1
Gouda 28%	10	1.1	94	12.3
Hushålls cheese 17%	10	1.9	86	13.4
Hushålls cheese 17%	10	1.6	85	14.4

Table AIV.2. *The 10 articles making the highest contribution to the CF associated with waste in the dairy department*

Article	Wasted mass (kg/store/yr)	Relative wasted mass (%)	Wasted CF (kg CO_2e/store/yr)	Aggregated share of department wasted CF (%)
Butter 75%	33	0.21	220	2.6
Cream 5dl 40%	31	0.75	160	4.6
Cream	25	0.60	130	6.2
Eggs 24-pack	86	0.32	130	7.7
Skim milk 0.5%	140	0.42	130	9.3
Medium fat milk 1.5%	120	0.20	110	10.6
Eggs 24-pack	69	0.42	100	11.8
Cream 40%	19	0.67	100	13.1
Medium fat milk 1.5%	99	0.11	95	14.2
Medium fat milk 1.5%	99	0.18	95	15.4

Table AIV.3. *The 10 articles making the highest contribution to the CF associated with waste in the deli department*

Article	Wasted mass (kg/store/yr)	Relative wasted mass (%)	Wasted CF (kg CO_2e/store/yr)	Aggregated share of department wasted CF (%)
Mamas meatballs	45	0.6	560	3.2
Family hotdogs	92	5.2	480	6.0
Hotdogs with skin	63	2.1	330	7.9
Salted rump steak	11	25	280	9.5
Meatballs	19	0.5	230	10.8
Meatballs	19	0.4	230	12.1
Prins sausage	43	4.6	220	13.4
Hot barbecue sausage	69	1.3	220	14.6
Barbecue sausage thick	37	5.5	200	15.8
Barbecue sausage thin	36	7.6	190	16.8

Table AIV.4. *The 10 articles making the highest contribution to the CF associated with waste in the meat department*

Article	Wasted mass (kg/store/yr)	Relative wasted mass (%)	Wasted CF (kg CO_2e/store/yr)	Aggregated share of department wasted CF (%)
Irish minced beef 20%	52	0.34	1 500	3.9
Imported minute steak	50	1.5	1 500	7.6
Minced beef 20%	34	0.36	1 000	10.1
Stew beef	33	2.6	950	12.5
Chuck steak rib	29	3.7	830	14.7
Minced beef 10-12%	21	0.22	610	16.2
Imported stew beef	21	5.5	600	17.8
Minute steak 9-12 slices	21	1.6	590	19.3
Sirloin steak	14	4.2	580	20.8
Minced veal 17%	20	4.5	570	22.2

Table AIV.5. *The 10 articles in the cheese department with the highest relative waste in terms of mass, given for six stores during five years*

Article	Sold mass (kg)	Wasted mass (kg)	Relative wasted mass (%)
Almkäse 28%	10	24	72
Bacon-flavoured cheeseballs	17	8	31
Raclette cheese	62	23	27
Jarlsberg 28%	220	78	26
Sörgård cheese 31%	24	8	24
Grated blue cheese 30%	139	38	22
Sour cream-flavoured cheeseballs	19	5	21
Goats cheese 23%	57	15	21
Garlic cheese 29%	86	22	21
Emmental	45	12	20

Table AIV.6. *The 10 articles in the dairy department with the highest relative waste in terms of mass, given for six stores during five years*

Article	Sold mass (kg)	Wasted mass (kg)	Relative wasted mass (%)
Raw eggs (deshelled)	21	24	54
Light crème fraiche 15%	10	6	38
Custard	73	43	37
Lactose-free milk 2%	28	14	33
Gourmet cottage cheese 10%	30	14	32
Milk drink ‘Bone Health’ 1%	600	260	30
Organic raspberry-flavoured sour milk	92	34	27
Yoghurt with cottage cheese	160	47	23
Milk drink ‘Immune’ 1%	890	250	22
Blueberry juice	570	160	22

Table AIV.7. *The 10 articles in the deli department with the highest relative waste in terms of mass, given for six stores during five years*

Article	Sold mass (kg)	Wasted mass (kg)	Relative wasted mass (%)
Head cheese	16	26	62
Everyday cold cuts	14	19	57
Friday luxury cold cuts	13	16	55
Sliced roast beef	15	12	46
Barbecue sausage	260	210	45
Barbecue sausage with cheese and bacon	210	170	45
Smoked lamb leg	250	200	45
Boiled ham with mustard	18	14	44
Liver pate	130	94	42
Crumbed ham	15	10	39

Table AIV.8. *The 10 articles in the meat department with the highest relative waste in terms of mass, given for six stores during five years*

Article	Sold mass (kg)	Wasted mass (kg)	Relative wasted mass (%)
Minced beef	15	33	69
Pork	90	100	53
Pork tenderloin with bacon	120	130	52
Pork skewers	39	36	48
Spicy chicken fillet	130	110	47
Pork liver	52	35	41
Sliced Angus beef	24	15	38
Grilled warm ribs	130	79	38
Thai spiced pork	190	110	37
Mini beef fillets for grilling	17	9.1	35